



Concord Scientific Corporation

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FINAL REPORT

ANALYSIS OF NITROGEN OXIDES

AIR QUALITY DATA

FOR THE GREATER VANCOUVER REGIONAL DISTRICT

1978-1981

Prepared for

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

by

Scott Diehl

Claude S. Davis

James E. Hunt

CONCORD SCIENTIFIC CORPORATION

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1. INTRODUCTION

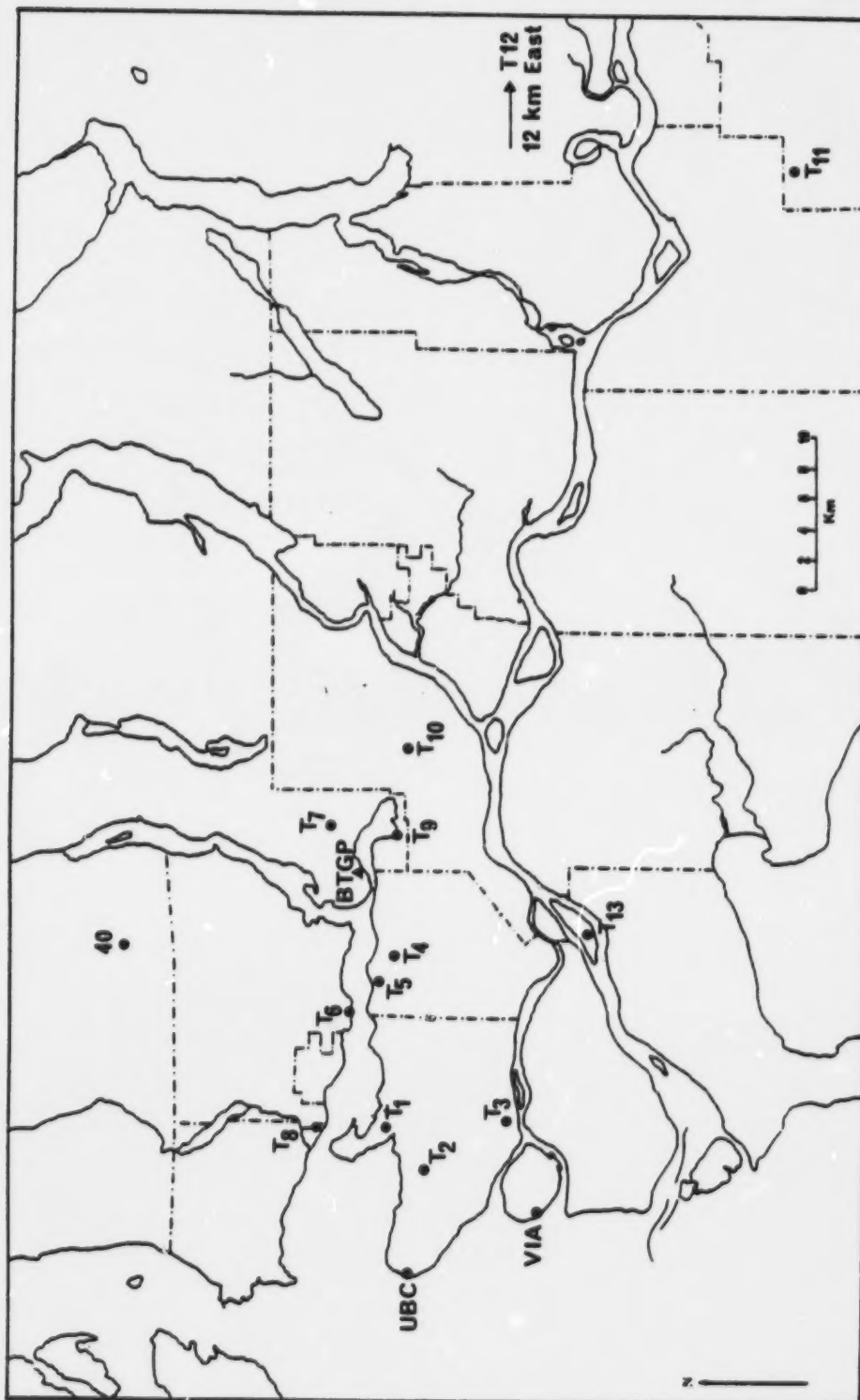
The application by British Columbia Hydro and Power Authority (BC Hydro) for a permit to operate the Burrard Thermal Generating Plant (BTGP) near Port Moody, includes the comprehensive assessment of potential environmental effects. The thorough understanding of the existing air quality in the BTGP environs, (see Figure 1.1) namely the Greater Vancouver Regional District (GVRD), represents one aspect of the environmental assessment. The relevant air quality parameters are the nitrogen oxides levels since the BTGP, which uses natural gas fuel, would generate nitrogen oxides (NO_x) emissions. The potential impact of these emissions on air quality in the region therefore needs to be evaluated.

Air quality data available for the GVRD includes hourly nitrogen dioxide (NO_2) measurements at several stations since 1978. Less extensive nitric oxide (NO) and total nitrogen oxides (NO_x) data are also available. The knowledge and understanding of the existing air quality in terms of the NO, NO_2 or NO_x levels are therefore essential in order to evaluate any impact that operation of the BTGP may have on these levels.

This report describes the analysis of the NO_x air quality data in the GVRD from 1978 to late-1981. The work program required for the analysis is detailed below and the general approach for executing the work program is outlined.



1-1 MAP OF GVRD SHOWING LOCATION OF MONITORING STATIONS



1.1 Statement of Work Program

The scope of work required is as follows:

- a) Analyze existing data for nitrogen oxides for all stations with respect to the distribution of concentrations observed and select "events" (exceedances and episodes) based on various trigger concentrations. Form a subset of the data associated with these events.
- b) Analyze the distribution of these "events" by time of year, time of day, duration, relationship between stations, etc.
- c) Provide a stand alone report outlining the results.

1.2 Approach to Data Analysis

All the available data for air quality and meteorological parameters for the GVRD (1978 - 1981) contained in the "GVRD Archive" (Concord Scientific Corporation, 1982) were accessed as required. The available NO , NO_2 and NO_x data in the GVRD archive are illustrated in Figure 1.2 and summarized in Tables 1.2, 1.2 and 1.3, respectively. The archive was compiled in December 1981.

The existing nitrogen oxides air quality data are examined primarily in terms of the nitrogen dioxide data since this is the only nitrogen oxide for which there is an ambient air quality standard. The annual,



FIGURE 1-2 GVRD NITROGEN OXIDES DATA AVAILABILITY
1978 - 1981

STATION	1978	1979	1980	1981
T5				
T6				
T7				
T8				
T10	..			
T2				
T3				
T1				
T4				
T9				
T1A				

KEY	NO	_____
	NO ₂	
	NO _x	_____



TABLE 1.1
Available Records for NO data in GVRD Archive

<u>Station</u>	<u>First Month/Year</u>	<u>Last Month/Year</u>
T5	1/80	11/81
T6	2/80	11/81
T7	1/80	11/81
T8	1/80	11/81
T10	1/80	11/81
T2	1/80	11/81
T3	1/80	11/81
T1	1/80	4/80
T4	1/80	11/81
T9	2/80	11/81
T1A	5/80	11/81



TABLE 1.2
Available Records for NO₂ data in GVRD Archive

Station	First Month/Year	Last Month/Year
T5	2/78	11/81
T6	2/78	11/81
T7	1/78	11/81
T8	1/78	10/81
T10	10/78	11/81
T2	1/78	11/81
T3	1/78	11/81
T1	1/78	3/80
T4	1/78	11/81
T9	1/78	11/81
T1A	4/80	11/81



TABLE 1.3
Available Records for NO_x data in GVRD Archive

<u>Station</u>	<u>First Month/Year</u>	<u>Last Month/Year</u>
T5	1/80	11/81
T6	2/80	11/81
T7	1/80	11/81
T8	1/80	11/81
T10	1/80	11/81
T2	1/80	11/81
T3	1/80	11/81
T1	1/80	4/80
T4	1/80	11/81
T9	2/80	11/81
T1A	5/80	11/81



seasonal, monthly and diurnal variation of the nitrogen oxides are each described.

Events (i.e. exceedances) during which elevated NO_2 levels occur are identified. Criteria for these exceedances are defined in terms of three selected trigger concentrations that are exceeded. The trigger concentrations selected were 49, 74 and 104 ppb. The highest of these is 50 % of the one hour national air quality maximum acceptable objective of 210 ppb. The temporal (i.e. annual, seasonal, monthly and diurnal) variations of the frequency of occurrence of exceedances, are then examined in detail. The interrelationships between the stations during exceedances and the spatial variation of NO_2 levels are briefly examined.

The inclusion of a duration for the exceedance of the trigger concentrations is desirable in order to eliminate short duration spikes that occur and also to define a reasonable minimum duration for an episode. These criteria also allowed the identification of a convenient number of days on which episodes occur (episode days) that would include a variety of meteorological conditions.

Additional criteria for episodes that define their spatial extent are presented. The episodes are then analyzed to describe their occurrence by station, time of day, month, season and year.

The frequency distributions of the hourly and daily maximum NO_2 levels are determined and two parameter lognormal distribution functions



derived using two methods (the quantile method and the maximum likelihood method). For each station and for each method, the geometric mean and the standard deviations are used to calculate the concentrations likely to be exceeded once per year ($x_{.01}$ for hourly data and $x_{.27}$ for daily maximum one hour data) and also the number of hours per year, N_x , that the concentration x (for $x = 210, 105$ and 75 ppb) may be exceeded. These values are compared with the appropriate observed values in order to determine which method more reliably describes the observed behaviour, and therefore may be used with confidence for predictive purposes.



2. ANALYSIS OF NITROGEN OXIDES AIR QUALITY DATA

2.1 Exceedances of Standards

Nitrogen dioxide (NO_2) is the only nitrogen oxide for which National Air Quality Objectives have been established. These objectives prescribe maximum desirable, maximum acceptable and maximum tolerable levels for specified averaging time periods.

The maximum desirable levels define the ultimate goals for air quality and provide a basis for an antidegradation policy for unpolluted parts of the country and for the continuing development of control technology. The maximum acceptable levels are intended to provide adequate protection against effects on soil, water, vegetation, materials, animals, visibility, personal comfort and well-being. Maximum tolerable levels denote concentrations that require abatement without delay to avoid further deterioration of conditions to an air quality that endangers the prevailing lifestyle or, ultimately, to an air quality that poses a substantial risk to public health.

The national air quality objectives for NO_2 are as follows:

<u>Time Base</u>	<u>Objective</u> $\mu\text{g m}^{-3}$ (ppb)		
	<u>Maximum Desirable</u>	<u>Maximum Acceptable</u>	<u>Maximum Tolerable</u>
1 hour	-	400 (210)	1000 (530)
24 hours	-	200 (110)	300 (160)
1 year (Arithmetic mean)	60 (30)	100 (50)	



Over the 4 year period, one exceedance of the 1 hour maximum acceptable level national air quality objective for NO_2 was recorded. This occurred at T7 (Anmore Elementary School) on October 12, 1979 (1600 hours). There was one occasion on which the 24 hour average maximum acceptable level (October 6, 1978, Station T1) was exceeded. There was no exceedance of the annual arithmetic mean maximum acceptable level, or of any of the tolerable objective levels.

2.2 Temporal Variation of Nitrogen Oxides Levels

2.2.1 Nitrogen Dioxide

Annual and Seasonal Variation

Annual and seasonal mean NO_2 concentrations for each station are summarized in Tables 2.1 and 2.2. The figures in parenthesis are the percentage of possible daily observations for each period (year or season).

The annual means show no consistent trend (stations with less than 60 % data recovery in any year were ignored) and suggest little variation in NO_2 levels.

The data in Table 2.1 were derived by defining seasons as follows: winter - January, February, March ; spring - April, May, June ; summer - July, August, September and fall as October, November, December.

The data for the seasonal means suggest that the lowest values occur in spring or summer but the poor data capture for some stations requires



Table 2.1
Annual Mean Nitrogen Dioxide Concentrations

Station	Location	Annual Mean (ppb)			
		1978	1979	1980	1981
T5	Confederation Park	20 (64)*	22 (84)	22 (87)	25 (55)
T6	GVRD Beach Works	19 (75)	18 (69)	22 (70)	22 (61)
T7	Anmore Elemen School	8 (38)	18 (64)	20 (88)	16 (70)
T8	Lions Gate STP	18 (83)	19 (95)	19 (84)	42 (4)
T10	Dept. of Highways	27 (8)	20 (41)	17 (96)	18 (57)
T2	GVRD Office	24 (84)	24 (83)	22 (99)	24 (14)
T3	Manitoba Works Yard	27 (82)	24 (76)	19 (85)	23 (47)
T1	B.C. Hydro Park	34 (31)	29 (89)	28 (23)	-
T4	Kensington Park	25 (91)	16 (58)	22 (88)	23 (76)
T9	Rocky Point Park	19 (77)	16 (44)	23 (27)	21 (87)
T1A	B.C. Hydro Park	-	-	29 (69)	33 (88)

* Numbers in parenthesis are the percent of possible daily observations for the year.



Table 2.2
Seasonal Mean Nitrogen Dioxide Concentrations (1978 - 1981)

Station	Location	Seasonal Mean (ppb)			
		Winter	Spring	Summer	Fall #
T5	Confederation Park	27 (44)*	16 (74)	22 (85)	25 (93)
T6	GVRD Beach Works	20 (53)	19 (71)	21 (86)	21 (70)
T7	Anmore Elemen School	16 (58)	4 (76)	18 (65)	21 (62)
T8	Lions Gate STP	22 (71)	15 (64)	16 (73)	22 (72)
T10	Dept. of Highways	17 (40)	15 (49)	21 (51)	17 (66)
T2	GVRD Office	24 (75)	23 (92)	23 (89)	23 (96)
T3	Manitoba Works Yard	25 (67)	21 (75)	20 (88)	31 (68)
T1	B.C. Hydro Park	34 (51)	30 (32)	24 (42)	32 (24)
T4	Kensington Park	23 (91)	21 (78)	23 (67)	22 (81)
T9	Rocky Point Park	20 (67)	14 (58)	22 (58)	21 (47)
T1A	B.C. Hydro Park	42 (22)	34 (44)	25 (49)	28 (32)

* Numbers in parenthesis are the percent of possible observations

Excludes Fall 1981



this suggestion to be viewed with caution.

Details of the frequency distributions of the annual and seasonal 24 hour average NO_2 levels are listed in Appendices 1 - 4 and 5 - 8, respectively.

Monthly and Diurnal Variations

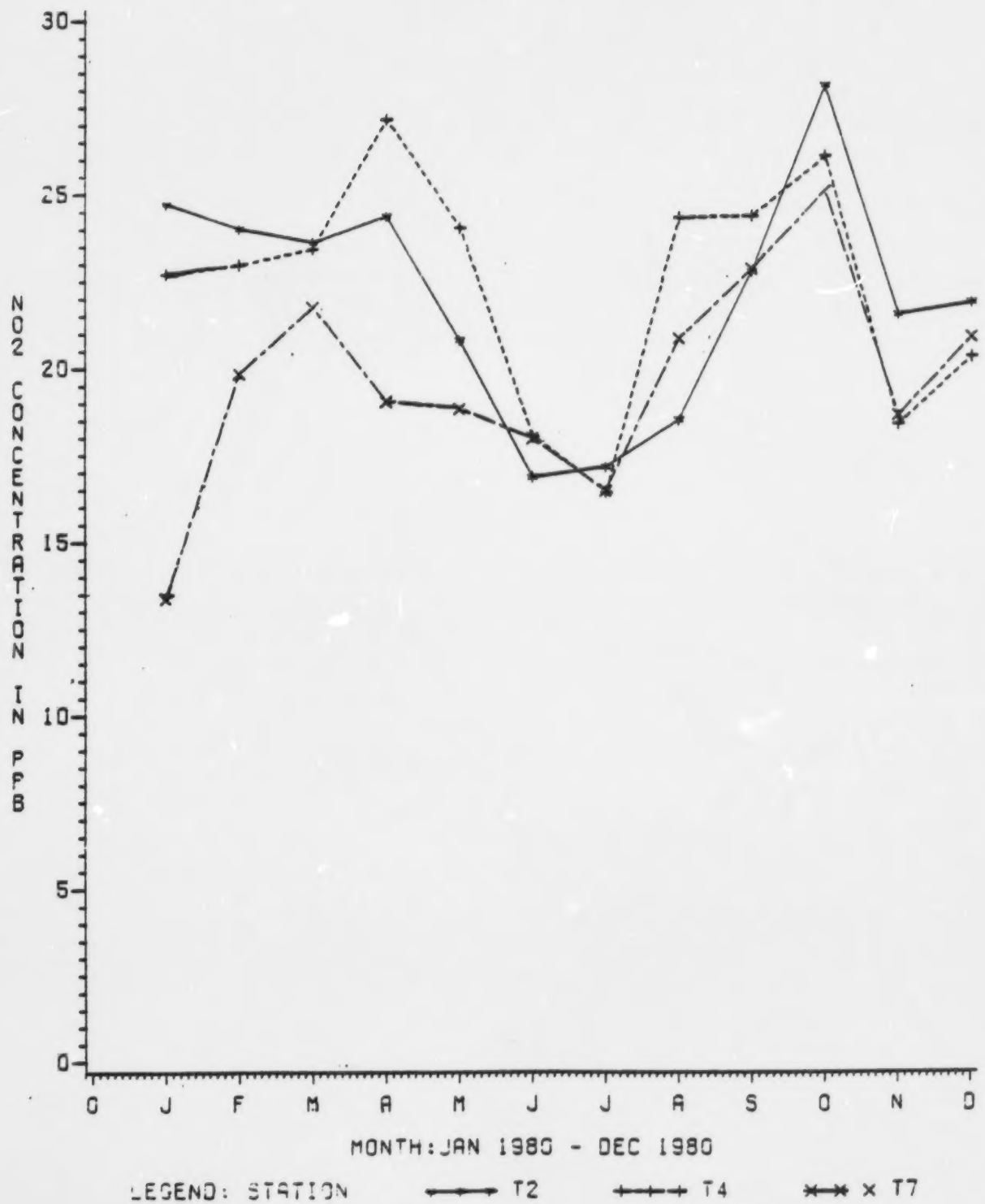
Stations T2, T4 and T7 have been selected as representatives from each of three geographic areas in the GVRD, these being the western, central and eastern areas respectively. These stations will be used to illustrate some of the monthly and diurnal variations of the NO_2 (also NO and NO_x) levels. Since NO data have been available only from 1980 and all the 1981 data were not available for inclusion in the archive, the illustrations will depict data for 1980. The data recovery for 1980 was not always ideal (i.e. > 75%), but are adequate for illustrating the main features of the temporal variation of the NO_2 (also NO and NO_x) levels.

The variation of the monthly mean NO_2 values indicates a pattern in which higher levels generally occur in the February - April and again in the September - November periods. These features are illustrated in Figure 2.1, in which the monthly means for stations T7, T2 and T4 during 1980 are plotted.

The diurnal variation of NO_2 is illustrated in Figures 2.2 - 2.5 for stations T2, T4 and T7. The figures show hourly means for four months (one month for each of the four seasons).



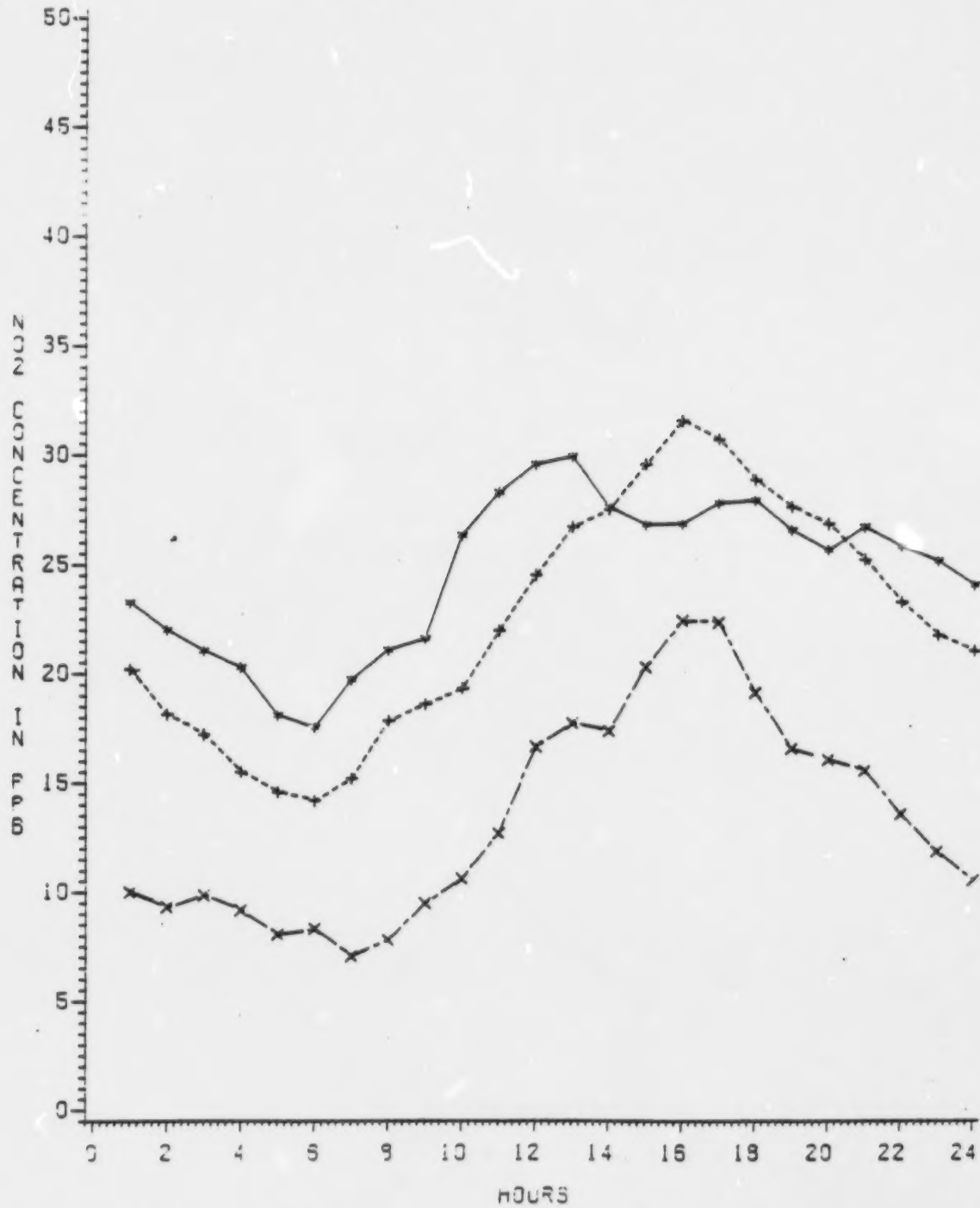
Figure 2.1
MONTHLY MEAN NITROGEN DIOXIDE LEVELS
AT SELECTED GVRD STATIONS
IN 1980



- 16 -

Figure 2.2

**DIURNAL VARIATION
MEAN NITROGEN DIOXIDE LEVELS
SELECTED GVRD STATIONS: JANUARY 1980**



LEGEND: STATION

—•— T2

- - - • - - - T4

—x— T7



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Figure 2.3
DIURNAL VARIATION
MEAN NITROGEN DIOXIDE LEVELS
SELECTED GVRD STATIONS: APRIL 1980

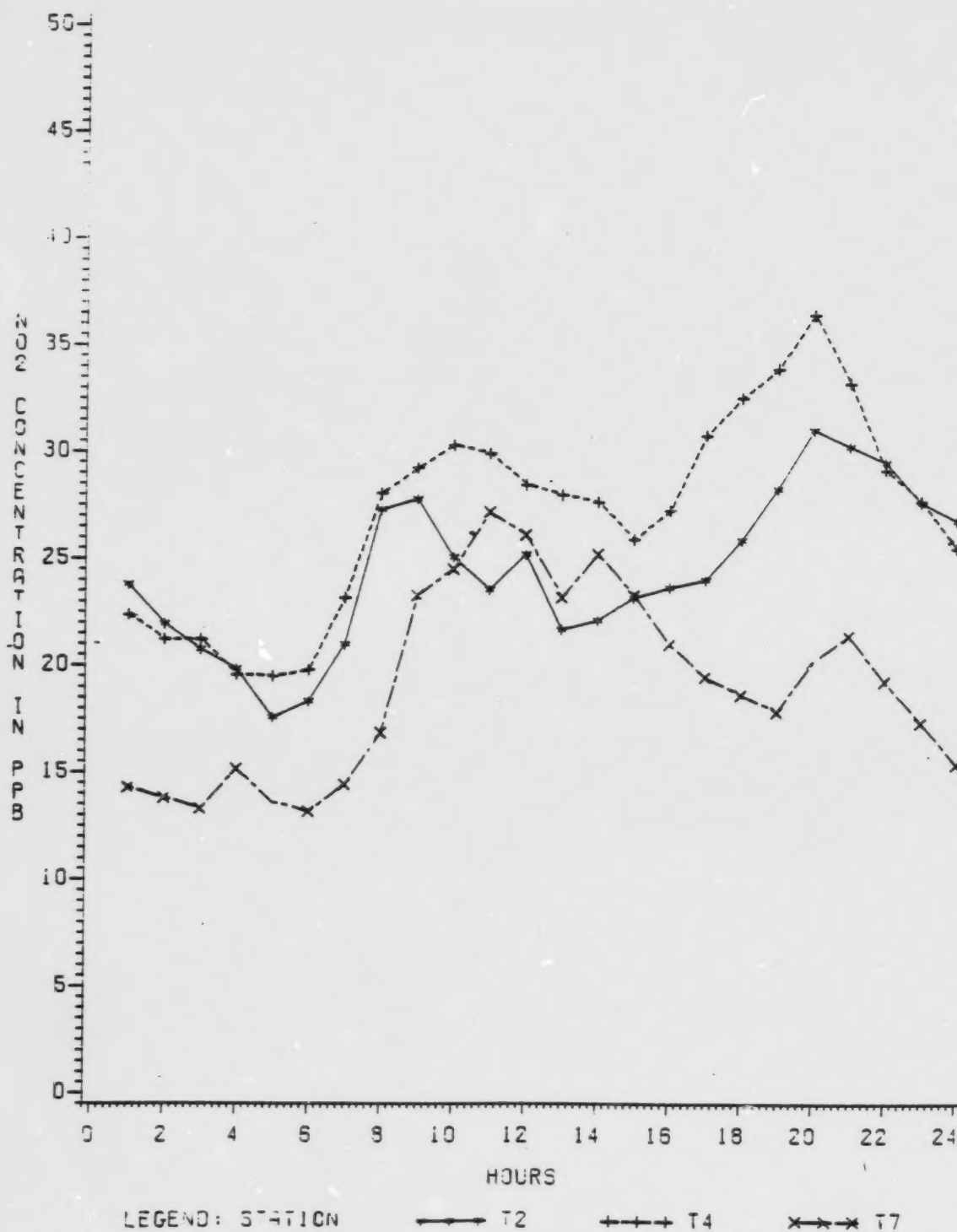


Figure 2.4
DIURNAL VARIATION
MEAN NITROGEN DIOXIDE LEVELS
SELECTED GVRD STATIONS: JULY 1980

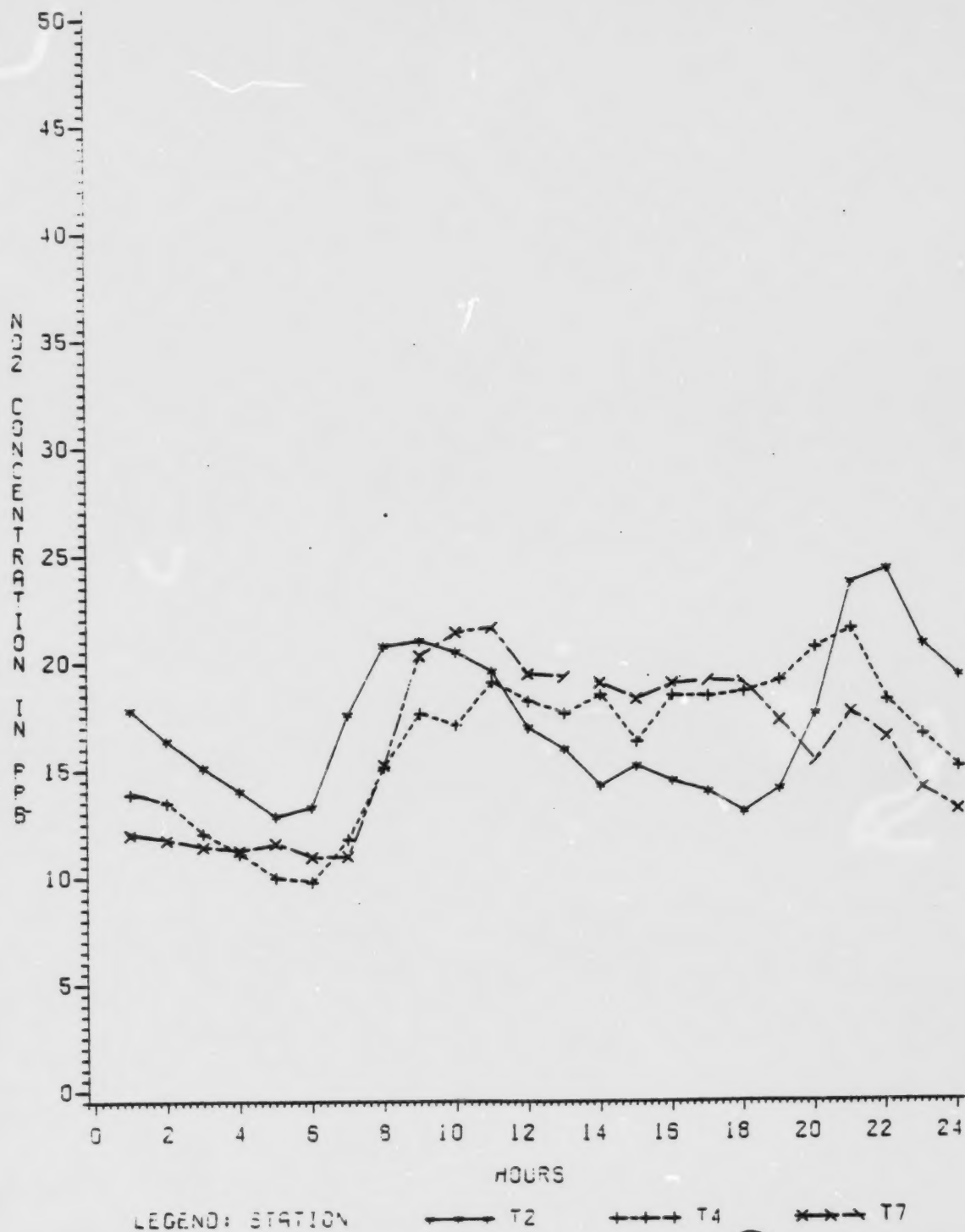
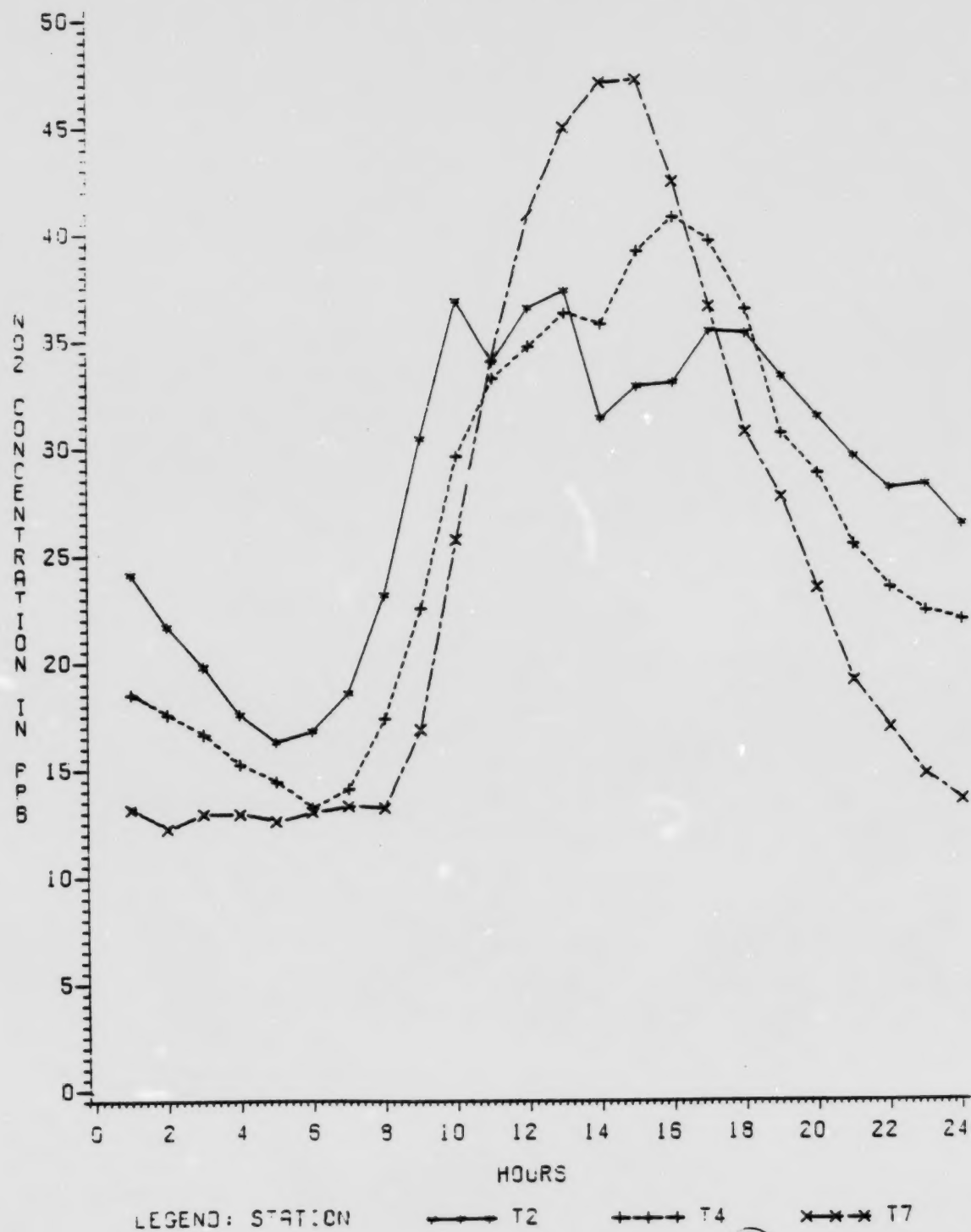


Figure 2.5
DIURNAL VARIATION
MEAN NITROGEN DIOXIDE LEVELS
SELECTED GVRD STATIONS: OCTOBER 1980



A common feature of the figures is the diurnal maximum. There is a consistent increase in NO_2 levels in the morning (starting at 0600 - 0900 hours). This increase is consistent with NO_2 resulting from nitrogen oxides emissions from mobile sources, i.e. morning traffic.

In some cases there are two NO_2 maxima (see Figures 2.3 and 2.4) which suggest the influence of afternoon traffic in accounting for the later peak.

2.2.2 Nitric Oxide

Annual and Seasonal Variation

Nitric oxide data have been available only since 1980. The statistical summaries of the data for 1980 and 1981 (Appendices 9 and 10) show that seven stations in 1980 and, so far, one station in 1981 have more than 75 % of data for the year. Table 2.3 is a summary of annual statistics for NO . The highest 1 % of the NO hourly average values and the maximum 24 hour mean levels at most stations in 1981 are significantly higher than in 1980. Unless there is a dramatic change in the NO levels in the outstanding period in 1981 it would be safe to conclude that NO levels would have increased significantly in 1981 over 1980.

The wide range of NO levels at the different monitoring stations is indicative of the strong influence of nearby sources. Notable is the low NO level at Station T7. The highest annual mean level of NO is found at T1A.



Table 2.3

Annual Mean Nitric Oxide Concentrations

Station	Location	Annual Mean (ppb)*	
		1980	1981
T5	Confederation Park	27 (85)	31 (48)
T6	GVRD Beach Works	36 (69)	39 (55)
T7	Anmore Elementary School	6 (86)	9 (59)
T8	Lions Gate STP	32 (81)	54 (5)
T10	Dept. of Highways	48 (91)	47 (48)
T2	GVRD Office	55 (97)	58 (67)
T3	Manitoba Works Yard	43 (77)	74 (38)
T1	B.C. Hydro Park	75 (26)	-
T4	Kensington Park	31 (86)	67 (67)
T9	Rocky Point Park	49 (26)	44 (76)
T1A	B.C. Hydro Park	79 (64)	97 (77)

* Numbers in parenthesis are the percent of possible daily observations for the year.



Since less than two years data are available the analysis of seasonal variations is not feasible. Any inferences on the seasonal variation of NO, can be obtained from examining the monthly variation of NO levels.

Monthly and Diurnal Variation of NO Levels

Figure 2.6 shows the variation of the monthly mean NO levels at three stations; T7, T2 and T4 for 1980. The NO levels are consistently higher during the colder months, September - March and probably reflect the influence of space heating related NO emissions. In addition, relatively low levels during the summer months are likely the result of meteorological conditions favourable to dispersion. During the summer months the conversion of NO to NO₂ is expected to be more rapid and in addition there will be more efficient depletion of NO by ozone which reaches higher levels in the summer than in winter.

The diurnal variation of NO is shown in Figures 2.7 - 2.10 in which the mean hourly values for each hour in the months of February, May, August and November 1980 are plotted. The diurnal variation is characterized by two peaks in the NO levels for stations T2 and T4. These peaks are typical of stations affected by mobile sources.

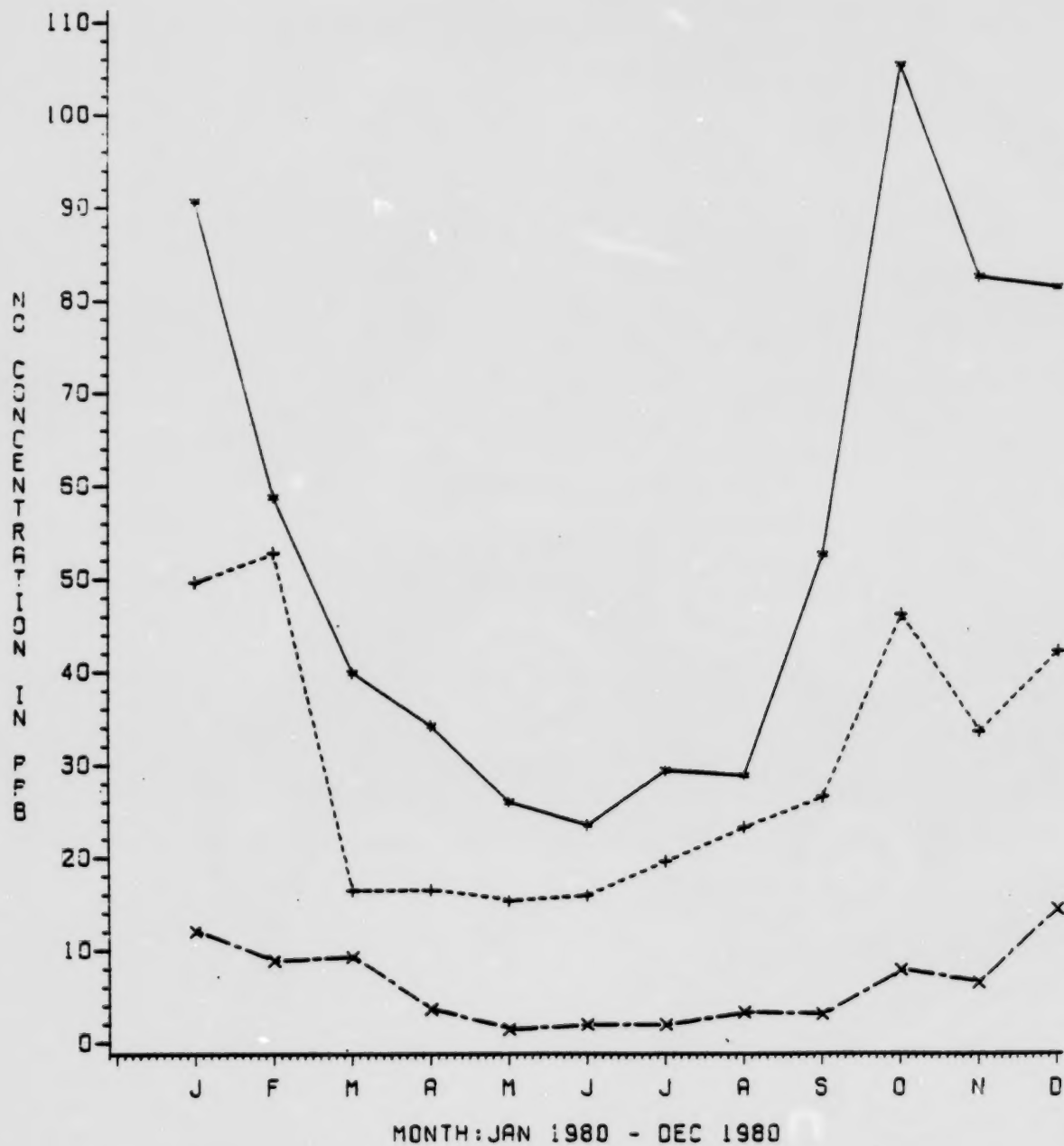
2.2.3 Total Nitrogen Oxides (NO_x)

Annual and Seasonal Variation

Data for total nitrogen oxides have been available since January



Figure 2.6
MONTHLY MEAN NITRIC OXIDE CONCENTRATIONS
AT SELECTED GVRD STATIONS:
IN 1980



LEGEND: STATION

— T2

- - - T4

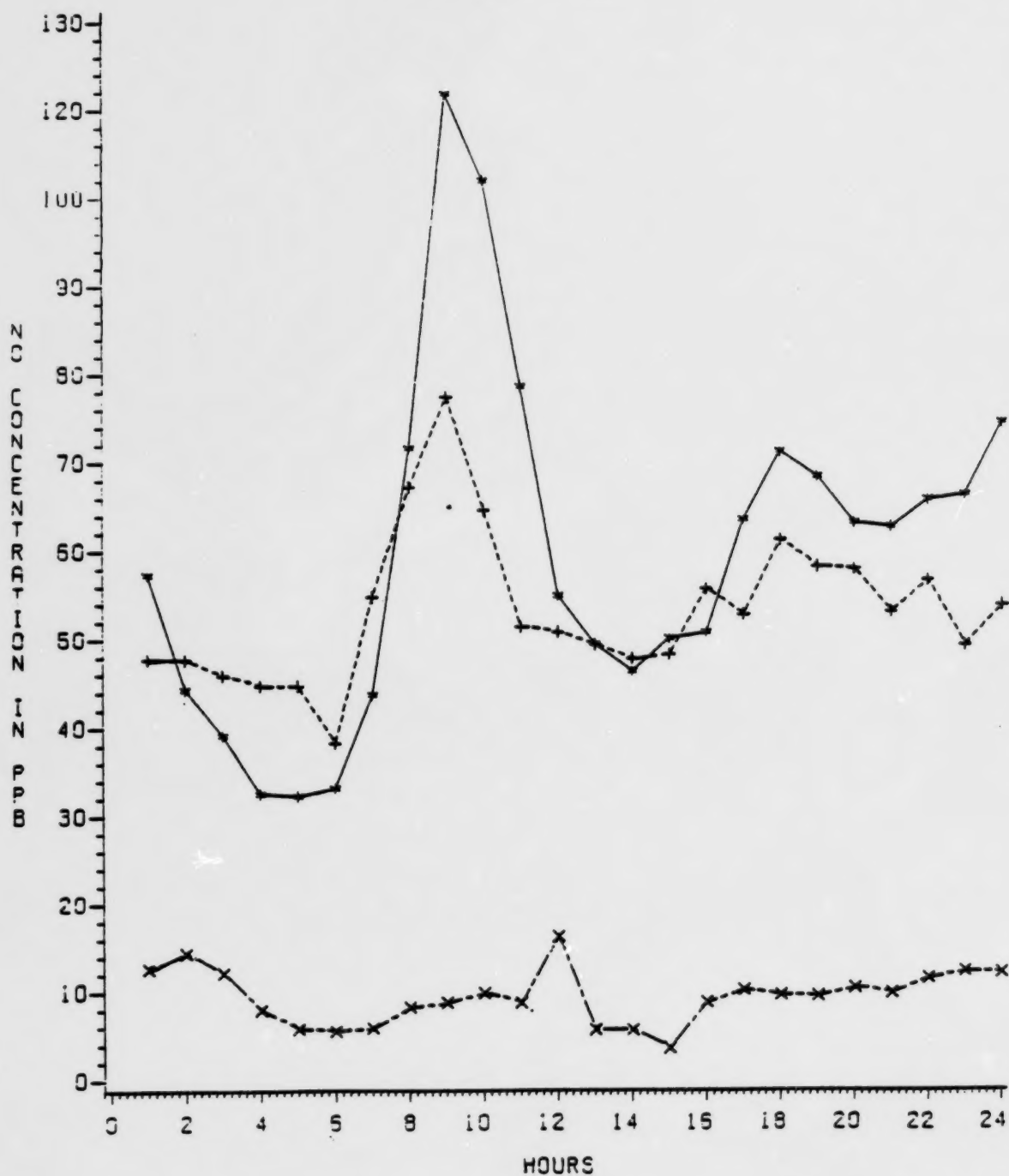
- . - . T7



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Figure 2.7

**DIURNAL VARIATION OF MEAN NITRIC OXIDE LEVELS
AT SELECTED GVRD STATIONS:
FEBRUARY 1980**



LEGEND: STATION

— T2

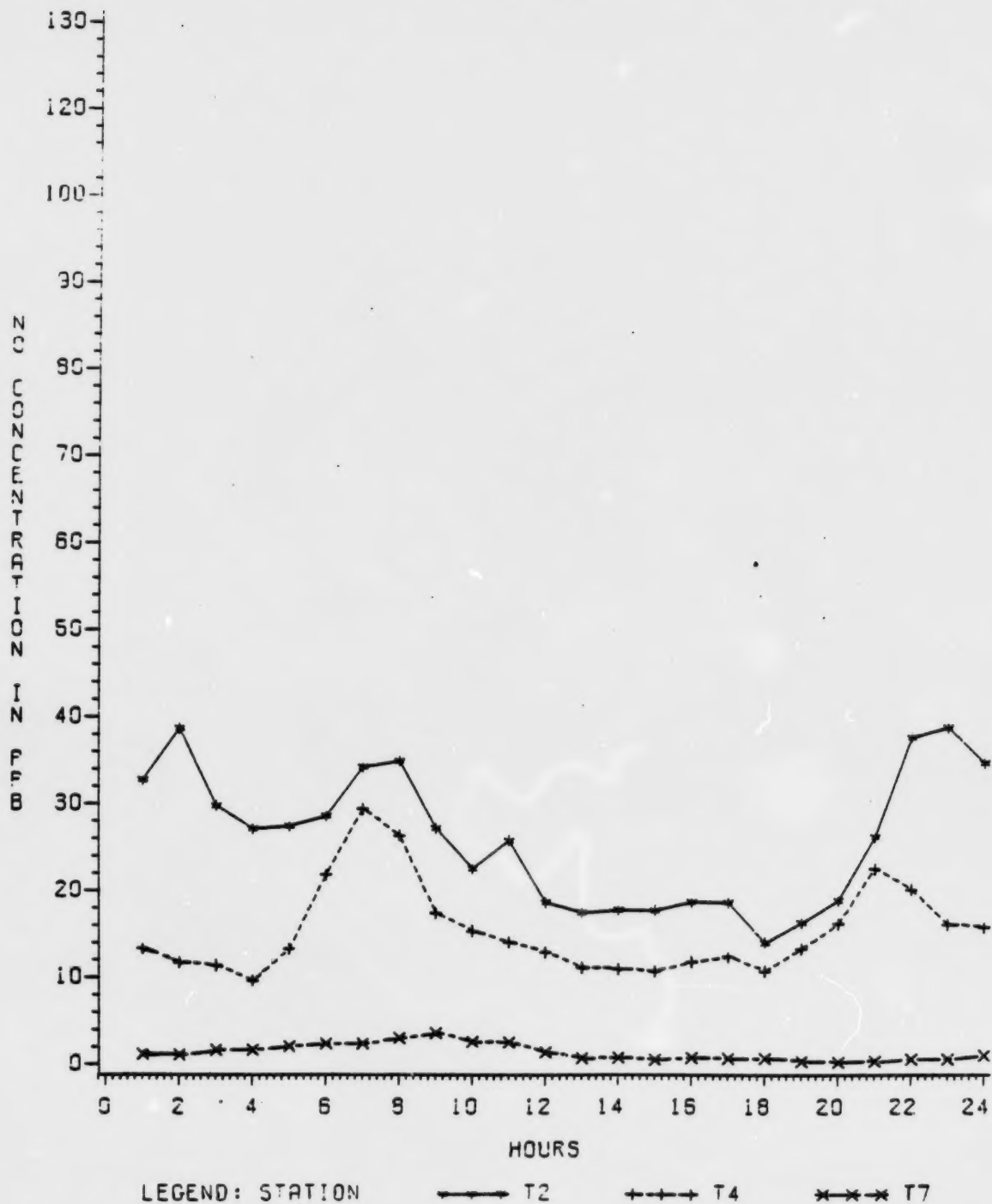
+ + + T4

x x x T7



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Figure 2.8
DIURNAL VARIATION OF MEAN NITRIC OXIDE LEVELS
AT SELECTED GVRD STATIONS:
MAY 1980



LEGEND: STATION

—•— T2

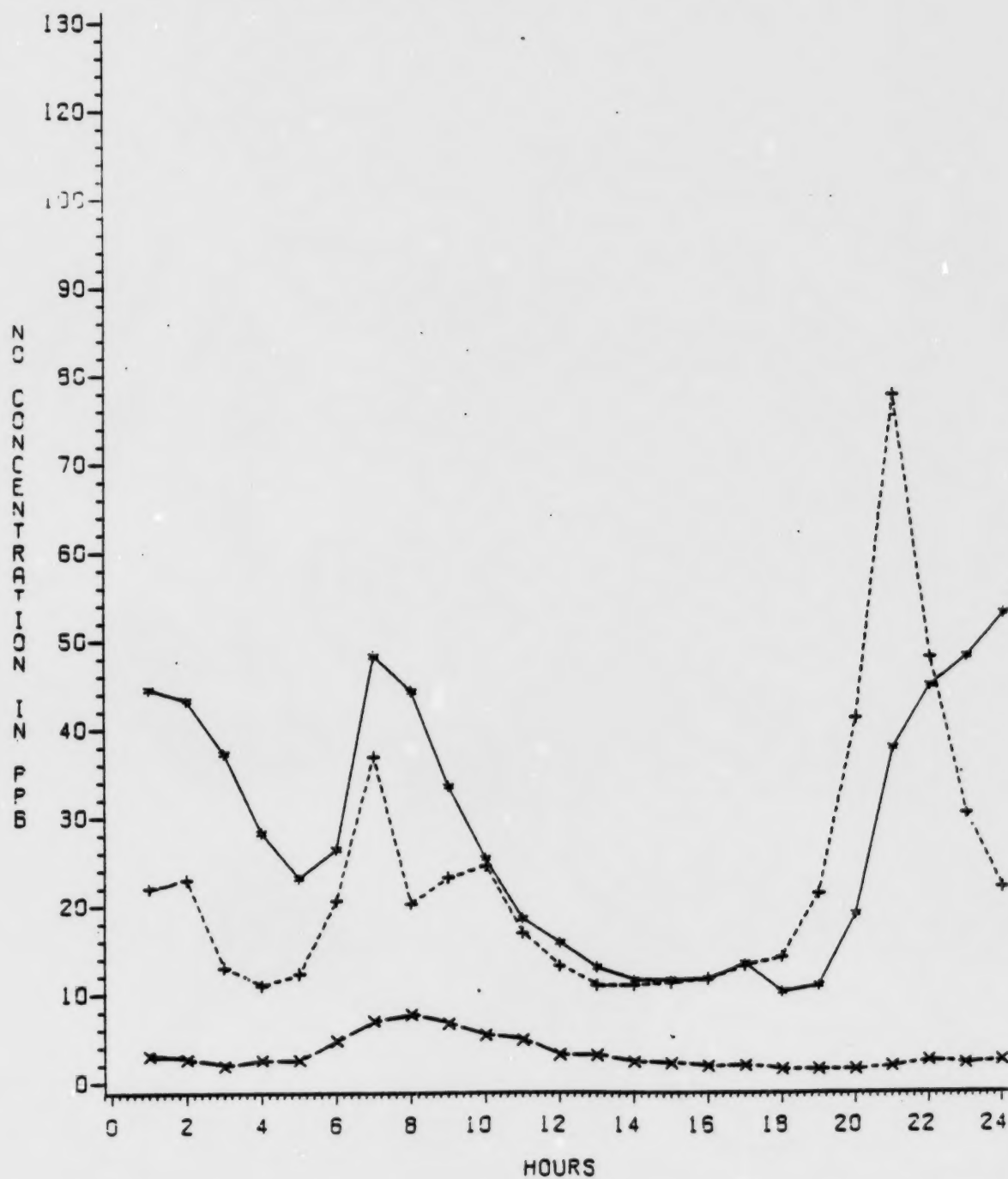
- - - T4

—x— T7



Figure 2.9

**DIURNAL VARIATION OF MEAN NITRIC OXIDE LEVELS
AT SELECTED GVRD STATIONS:
AUGUST 1980**



LEGEND: STATION

—●— T2

- - - + - - T4

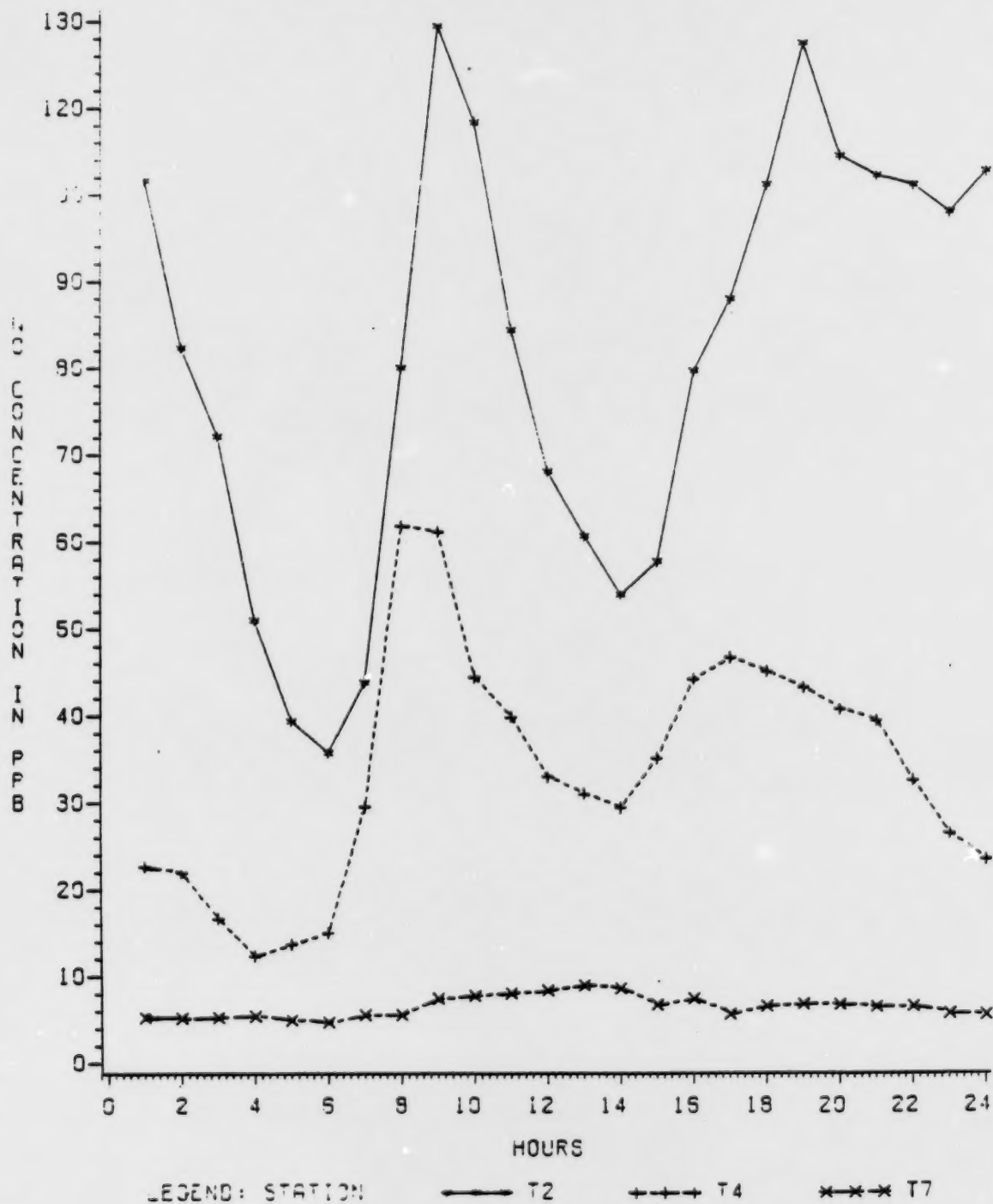
- x - x - x T7



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Figure 2.10

**DIURNAL VARIATION OF MEAN NITRIC OXIDE LEVELS
AT SELECTED GVRD STATIONS:
NOVEMBER 1980**



1980. Statistical summaries of the annual data are presented in Appendices 11 and 12. Annual means and the percentage of data for each station are given in Table 2.4. The lowest annual mean NO_x level is found at station T7 while the highest is at T1A. The strong influence of local sources of NO_x is again apparent in view of the wide range of NO_x levels found at the various stations.

The seasonal variation of NO_x levels may be discerned only on the basis of the limited data for less than two years. The seasonal variation may be therefore just as adequately determined by examining the monthly variation of NO_x levels.

Monthly and Diurnal Variation of NO_x

The variations of NO_x levels at 3 stations during 1980 are shown in Figure 2.11. The pattern is very similar to that for NO in which highest levels at each station are found in the winter months.

The diurnal variations of NO_x at selected stations are shown in Figures 2.12 - 2.15. The variation for stations T2 and T4 show two peaks undoubtedly due to NO emissions from morning and evening traffic. In addition the depletion of NO_x by reaction with hydrocarbons would be a significant factor in reducing the NO_x levels in daylight hours.



Table 2.4

Annual Mean Total Nitrogen Oxides Concentrations

<u>Station</u>	<u>Concentration / ppb *</u>	
	<u>1980</u>	<u>1981</u>
T5	50 (85)	58 (48)
T6	59 (68)	62 (55)
T7	27 (86)	26 (60)
T8	51 (81)	92 (4)
T10	66 (91)	64 (48)
T2	77 (97)	82 (67)
T3	58 (79)	91 (39)
T1	106 (26)	
T4	54 (85)	91 (66)
T9	73 (27)	66 (76)
T1A	110 (55)	130 (77)

* Numbers in parenthesis are the percent of possible daily observations for the year.



Figure 2.11

**MONTHLY MEAN TOTAL NITROGEN OXIDES
AT SELECTED GVRD STATIONS
IN 1980**

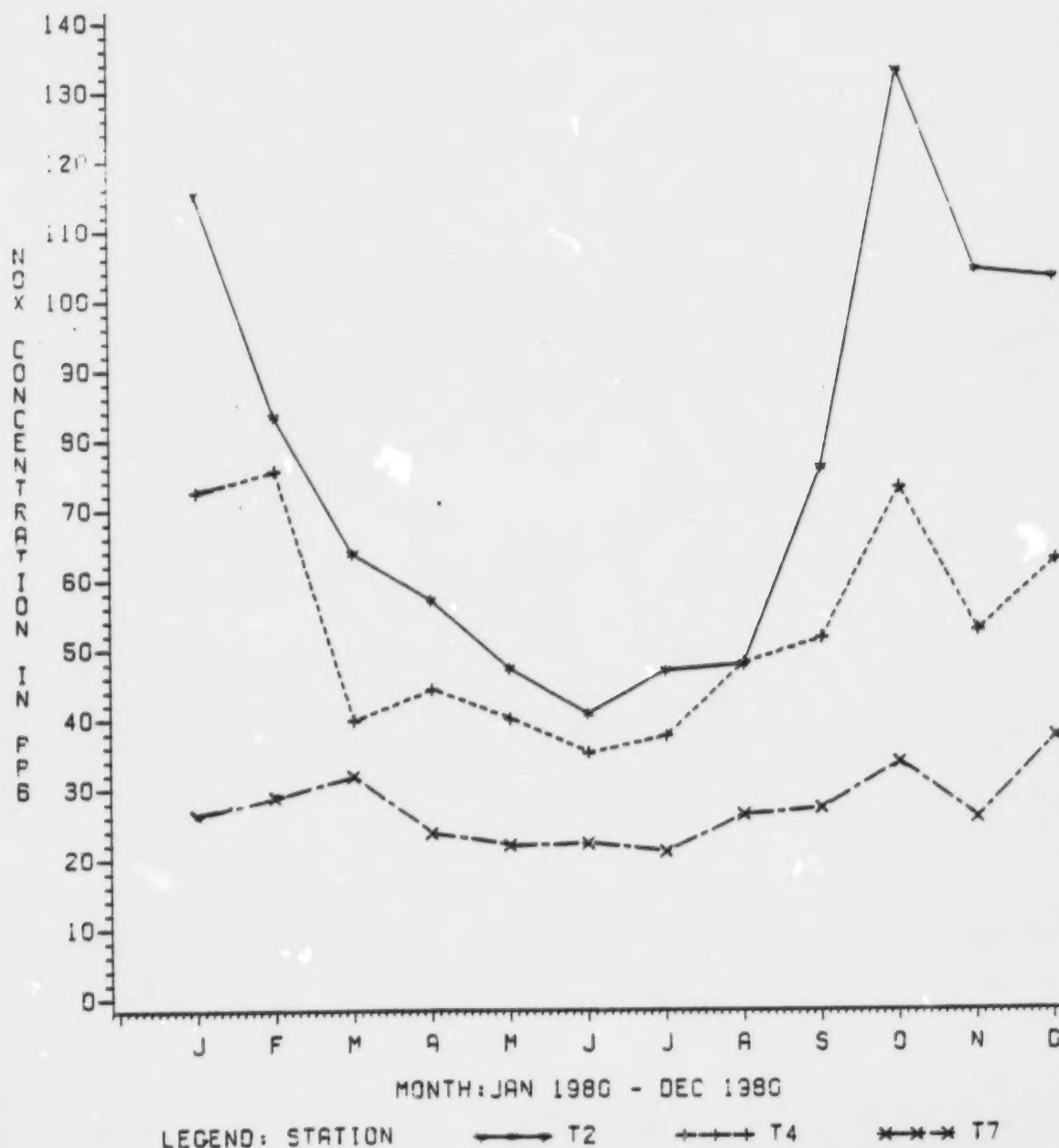


Figure 2.12
DIURNAL VARIATION
MEAN TOTAL NITROGEN OXIDES LEVELS
SELECTED GVRD STATIONS: FEBRUARY 1980

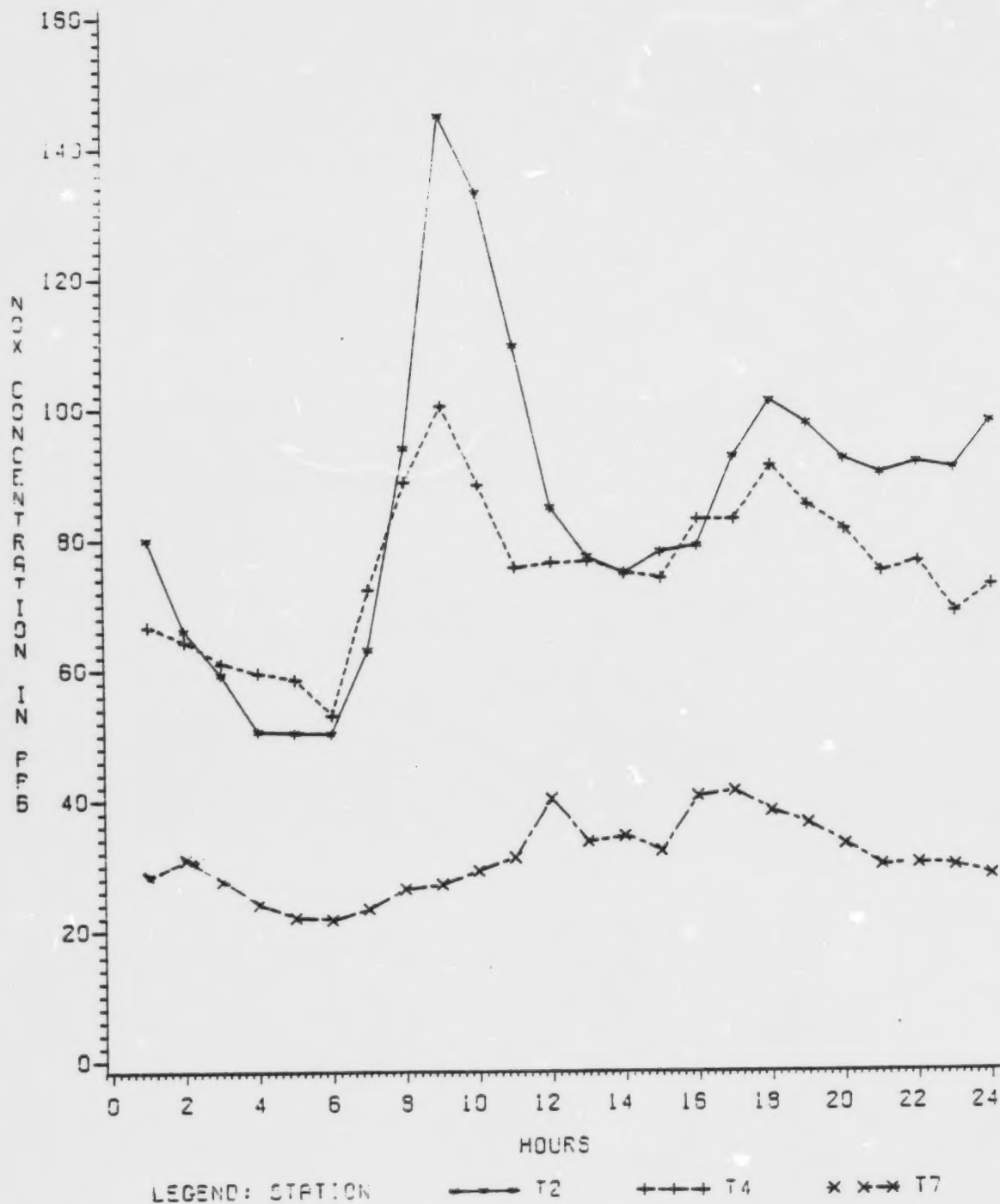
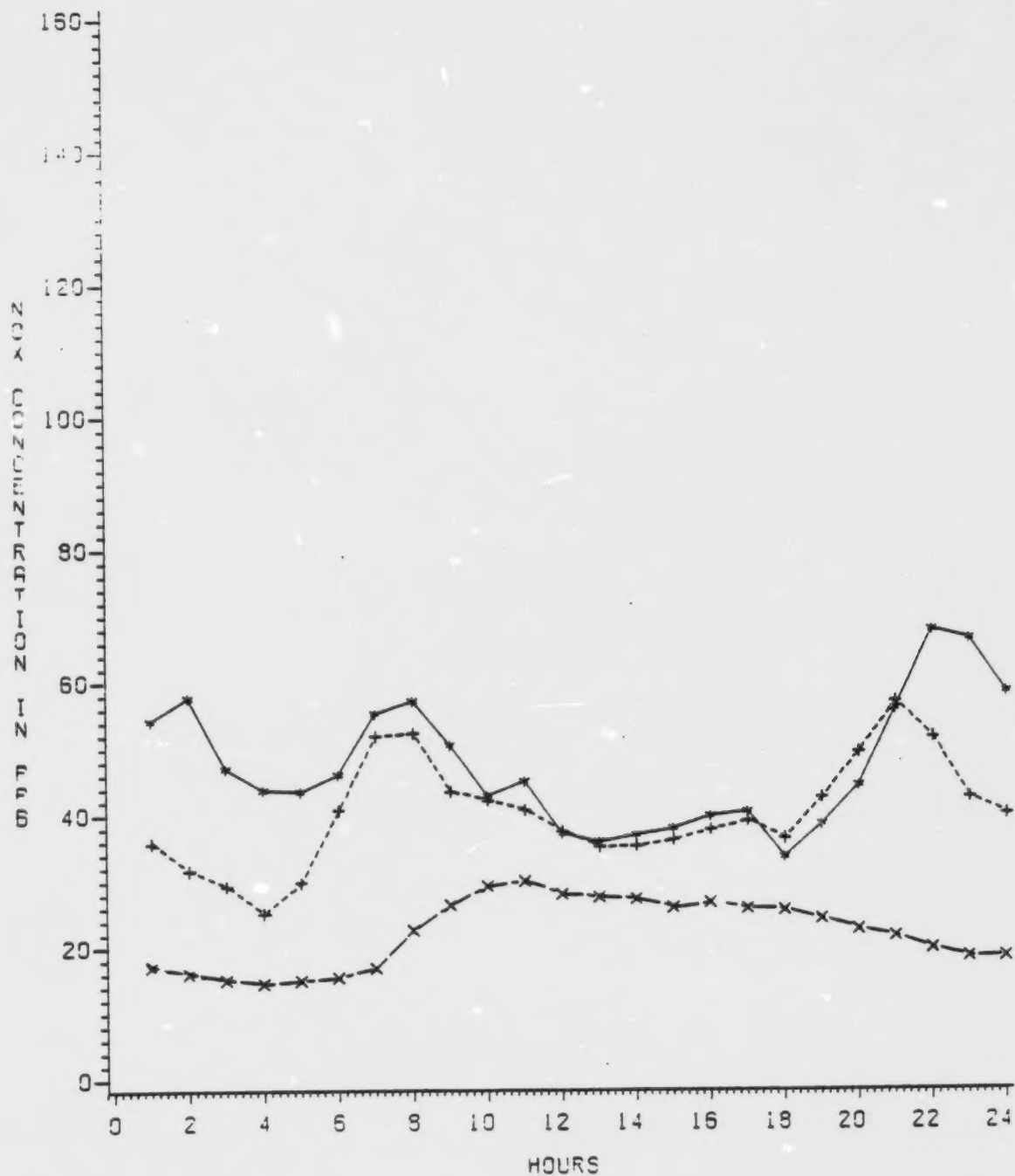


Figure 2.13
DIURNAL VARIATION
MEAN TOTAL NITROGEN OXIDES LEVELS
SELECTED GVRD STATIONS: MAY 1980



LEGEND: STATION

—•— T2

-+--+ T4

- T7



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Figure 2.14

**DIURNAL VARIATION
MEAN TOTAL NITROGEN OXIDES LEVELS
SELECTED GVRD STATIONS: AUGUST 1980**

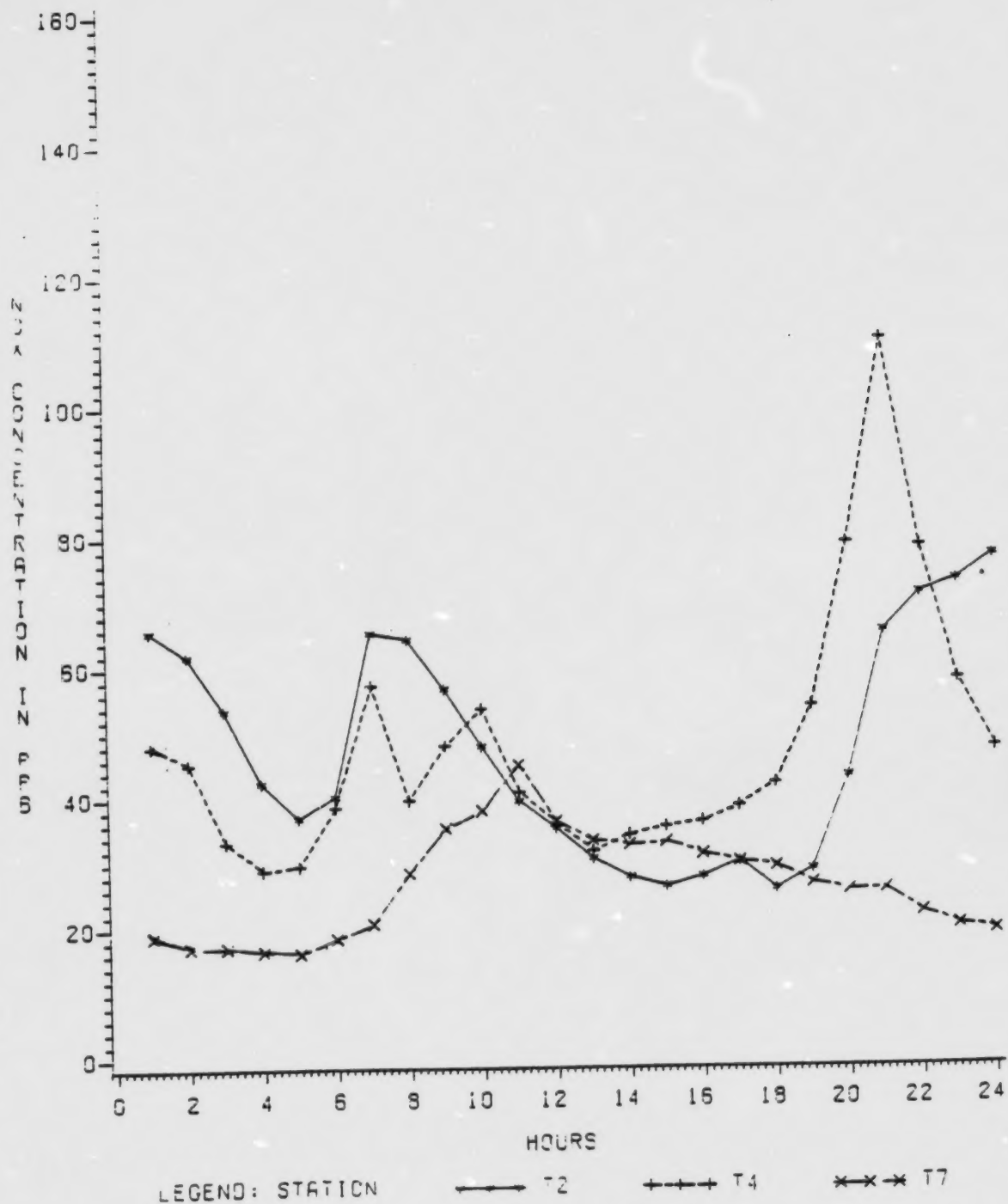
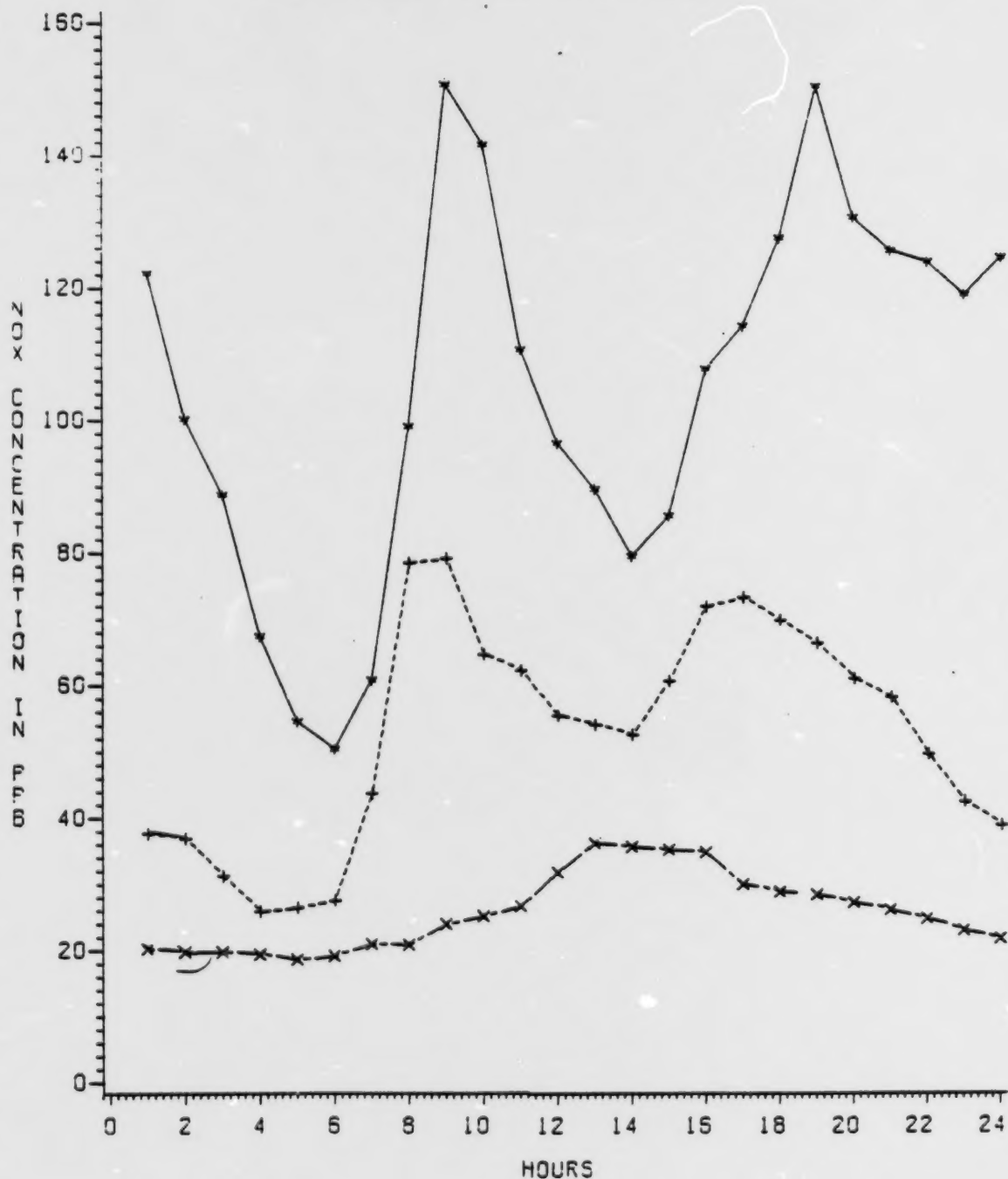


Figure 2.15
DIURNAL VARIATION
MEAN TOTAL NITROGEN OXIDES LEVELS
SELECTED GVRD STATIONS: NOVEMBER 1980



LEGEND: STATION

—•— T2

- - - • - - - T4

x x x T7



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3. ANALYSIS OF NO₂ TRIGGER LEVEL EXCEEDANCES AND EPISODES

3.1 Criteria for Exceedances and Episodes

Three different NO₂ concentrations, 49, 74 and 104 ppb, were selected as trigger concentrations. An hourly NO₂ concentration greater than the trigger concentration is defined as an exceedance of the specified trigger concentration.

Cases where the trigger concentration is exceeded for four or more consecutive hours are defined as episodes.

A discussion of the exceedances is given in Section 3.2. Episodes based on trigger concentrations of 104, 74 and 49 ppb were identified and these are discussed in Section 3.3. A summary of the numbers of exceedances and episodes (see Table 3.1) should be considered bearing in mind the different extents of data recovery at each station.

3.2 Exceedances of Trigger Concentrations

The frequencies of exceedances of 104 and 74 ppb at the various stations for each month each year are given in Tables 3.2 and 3.3 respectively.

3.2.1 Exceedances by Station

Examination of Table 3.2 shows that station T6 recorded the



Table 3.1: NO₂ Exceedances and Episodes Based on Different Trigger Concentrations

Trigger Concentration/ppb	Duration/ Hours	Total Hrs. of Exceedance	Station* Events	Days [#]
104	≥ 1	418	182	89
74	≥ 1	1950	641	284
104	≥ 4		24	16
74	≥ 4		152	79
49	≥ 4		762	

* Records with one or more exceedance or with episode.

[#] Different days on which one or more exceedance or episode occurred.



Table 3.2: Frequencies of NO₂ Exceedances of Trigger Concentrations at Each Station.

Station	Frequency										
	Trigger Concentration	74 ppb					104 ppb				
		1978	1979	1980	1981	Total	1978	1979	1980	1981	Total
T5		37	106	88	51	282	8	27	19	11	65
T6		52	84	90	85	311	10	23	25	18	76
T7		3	101	57	39	200	0	41	10	7	58
T8		14	52	12	25	103	3	14	1	3	21
T10		42	20	46	39	147	6	4	9	10	29
T2		10	44	13	25	92	0	7	3	4	14
T3		35	16	6	7	64	3	0	1	2	6
T1		84	86	2	*	172	24	8	0	*	32
T4		51	9	44	64	168	6	5	13	11	35
T9		30	35	32	81	178	5	13	7	15	40
T1A		*	*	52	181	233	*	*	3	39	42
		358	553	442	597	1950	65	142	91	120	418

* Missing/unavailable data.



Table 3.3: Frequency of Occurrence of Exceedances of
Trigger Concentrations by Month.

Month	Frequency										
	Trigger Concentration	74 ppb					104 ppb				
		1978	1979	1980	1981	Total	1978	1979	1980	1981	Total
Jan		8	106	20	135	269	1	22	5	26	54
Feb		9	9	7	36	61	0	0	0	2	2
Mar		9	22	11	109	151	1	0	0	26	27
Apr		14	20	9	2	45	0	4	0	0	4
May		8	5	48	13	74	0	0	4	5	9
Jun		25	11	3	2	41	2	5	0	0	7
Jul		27	14	12	22	75	0	0	1	5	6
Aug		7	20	11	27	65	0	1	3	1	5
Sep		15	113	97	105	330	3	33	20	30	86
Oct		202	140	196	94	632	56	51	54	19	180
Nov		31	91	22	52	196	2	26	4	6	38
Dec		3	2	6	#	11	0	0	0	#	0
Total		358	553	442	597	1950	65	142	91	120	418

Data unavailable



highest number of exceedances of 74 and 104 ppb for the four year period. This was in spite of the relatively low data recovery for this station, where only in 1978 was the data recovery > 75 % (see Table 2.1 for annual data recoveries for NO_2). Stations T3, T2 and T8 had the lowest numbers of exceedances of 74 and 104 ppb respectively. The data recoveries for these three stations were in excess of 75 % for 3 of the 4 years. Stations T2, T3 and T8 are the most westerly stations and these stations are likely to be upwind of NO_x sources in the Burrard Inlet area.

The highest numbers of exceedances of 74 or 104 ppb in any single year were recorded at station T1A in 1981. This station commenced operation in April of 1980 and replaced station T1 which was located ~ 100 m nearby. The significantly different station characteristics (sampling inlet) and site characteristics (construction and traffic patterns) resulted in the designation of a distinct station identity in the NAPS network. The data from stations T1 and T1A have been treated as separate records in this report as in the NAPS network in spite of their proximity.

The very different extents of NO_2 data recovery at T1 and T1A for the four years together with the station and site characteristics previously cited, do not allow the conclusive assessment of the relative impact of NO_2 levels at T1A or T1 compared to other stations.

The complexity of the terrain, the multiplicity of NO_x sources and the different extents of data recovery at other stations, preclude more detailed analysis or formulation of simple relationships between the sources and NO_2 exceedances at various stations.



3.2.2 Temporal Variation of Exceedances

3.2.2.1 Distribution of exceedances by month and season:

Table 3.3 details the numbers of exceedances occurring by month for each of the four years and for the total period (see also Figure 3.1). The exceedances occur most frequently from September to January, i.e. in the fall and early winter. The peculiar feature of the monthly distribution of the exceedances is the absence of, or very few, exceedances in December, while both November and January have significantly larger numbers of exceedances.

The air quality data was re-examined to determine possible explanations for this feature. Analysis of the NO_2 records did not reveal any lower data recovery for December compared to other months. Meteorological features peculiar to December are likely to account for the absence of exceedances in this month.

The predominance of exceedances of 74 or 104 ppb occurring in September - November is also shown in Tables 3.4 and 3.5 in which the exceedances at each station for various months of the year are tabulated.

3.2.2.2 Diurnal variation of exceedances:

The diurnal pattern of NO_2 levels has already been discussed. Of the days that showed exceedances, the frequencies with which the daily maximum NO_2 levels occurred for each hour of the day were determined.



FIGURE 3-1 : MONTHLY VARIATIONS OF EXCEEDANCES
OF NO₂ TRIGGER CONCENTRATIONS

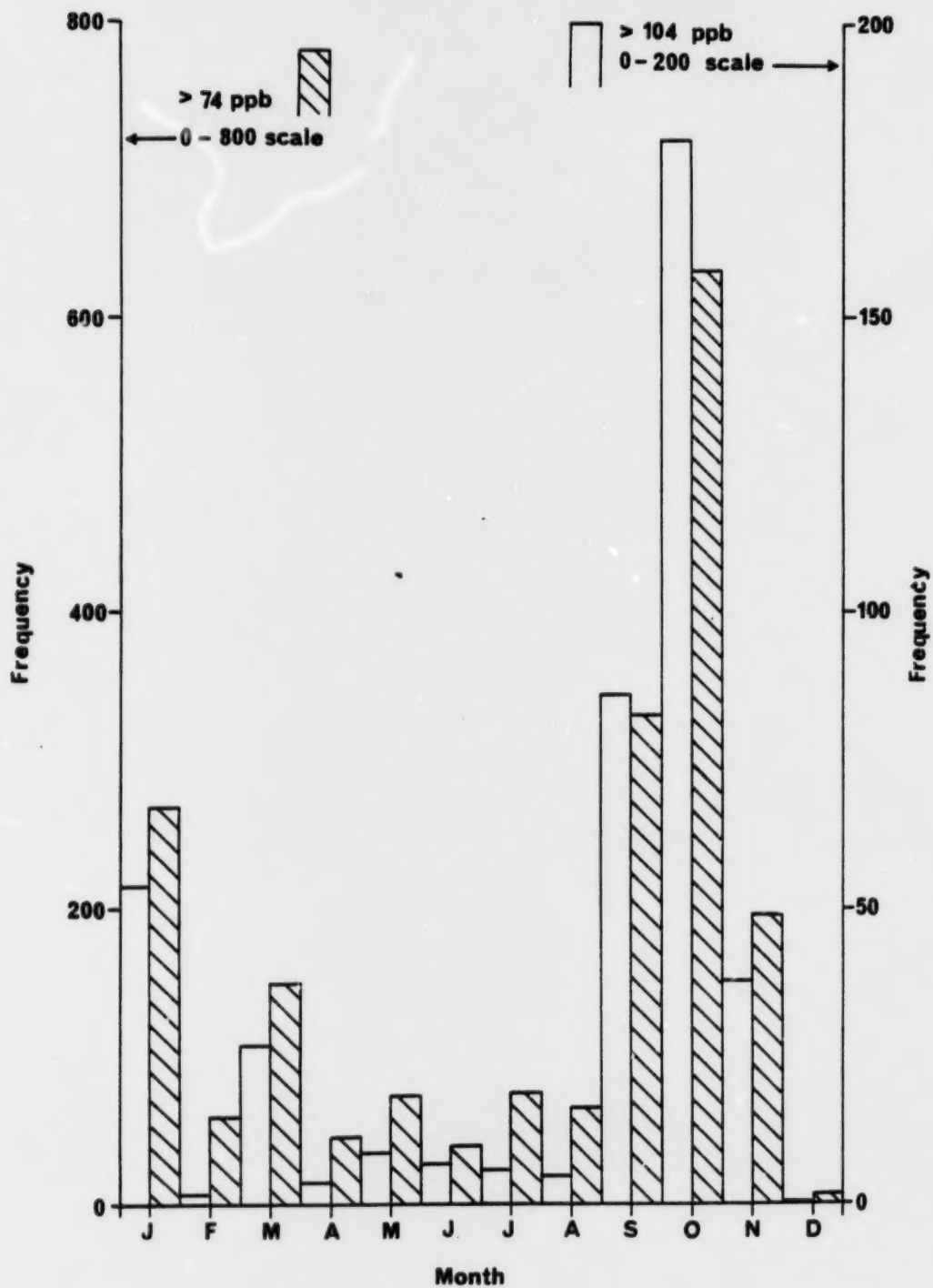


Table 3.4: Distribution of Exceedances of 104 ppb by
Station for Each Month

No. of Hours for NO₂ > 104 ppb

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
T5	8	0	0	0	0	0	0	0	12	28	17	0	65
T6	8	0	3	0	4	1	6	4	23	22	5	0	76
T7	6	0	0	0	0	5	0	0	12	34	1	0	58
T8	11	0	0	1	0	0	0	0	1	4	4	0	21
T10	0	0	1	0	4	0	0	0	5	14	5	0	29
T2	0	0	0	0	0	0	0	0	7	6	1	0	14
T3	0	0	0	0	0	0	0	0	2	4	0	0	6
T1	2	0	0	3	0	1	0	0	0	26	0	0	32
T4	5	0	0	0	0	0	0	1	10	18	1	0	35
T9	8	0	1	0	1	0	0	0	8	20	2	0	40
T1A	6	2	22	0	0	0	0	0	6	4	2	0	42
Total	54	2	27	4	9	7	6	5	86	180	38	0	418



Table 3.5: Distribution of Exceedences of 74 ppb
by Station for Each Month.

No. of Hours for NO₂ > 74 ppb

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
T5	44	6	6	2	2	1	7	11	56	82	58	7	282
T6	46	3	12	6	26	2	35	22	55	69	33	2	311
T7	16	4	12	5	4	11	5	6	35	93	8	1	200
T8	30	1	3	3	0	0	1	0	6	41	18	0	103
T10	7	0	4	0	7	0	6	5	29	71	18	0	147
T2	9	2	4	5	0	2	1	0	24	31	14	0	92
T3	3	1	3	1	0	2	5	0	16	17	16	0	64
T1	40	7	6	11	4	10	4	0	10	80	0	0	172
T4	19	0	3	9	6	9	4	9	38	59	12	0	168
T9	33	6	6	1	2	2	1	10	41	64	12	0	178
T1A	22	31	92	2	23	2	6	2	20	25	7	1	233
Total	269	61	151	45	74	41	75	65	330	632	196	11	1950



These data are tabulated in Table 3.6 and illustrated in Figure 3.2. The peak NO_2 levels generally occurred between 0800 and 2100 hours with most peaks occurring at 1300 for exceedances of 74 ppb and at 1400 for exceedances of 104 ppb.

3.2.3 Spatial Distribution of NO_2 Levels

The interrelationships between NO_2 levels at various stations were investigated by performing preliminary interpretation of factor analysis using the available NO_2 concentration data for all hours when an exceedance of 74 ppb occurred. There were 1135 different hours when these exceedances occurred and available data for these hours were selected for performing the factor analysis. For this analysis data from station T1 and T1A were combined.

A short description of factor analysis is presented in Appendix 13 together with some of the intermediate data generated in the course of the analyses. Only an outline of the capabilities of factor analysis is stated here together with the results of applying the method to the data set already defined.

In the present context, factor analysis will seek to determine the existence of any interrelationships between NO_2 levels at the various stations. The analysis indicated four factors would suffice for explaining the data. Manifestation of the interrelationships between stations is given by stations having similar magnitudes of the factor loadings.

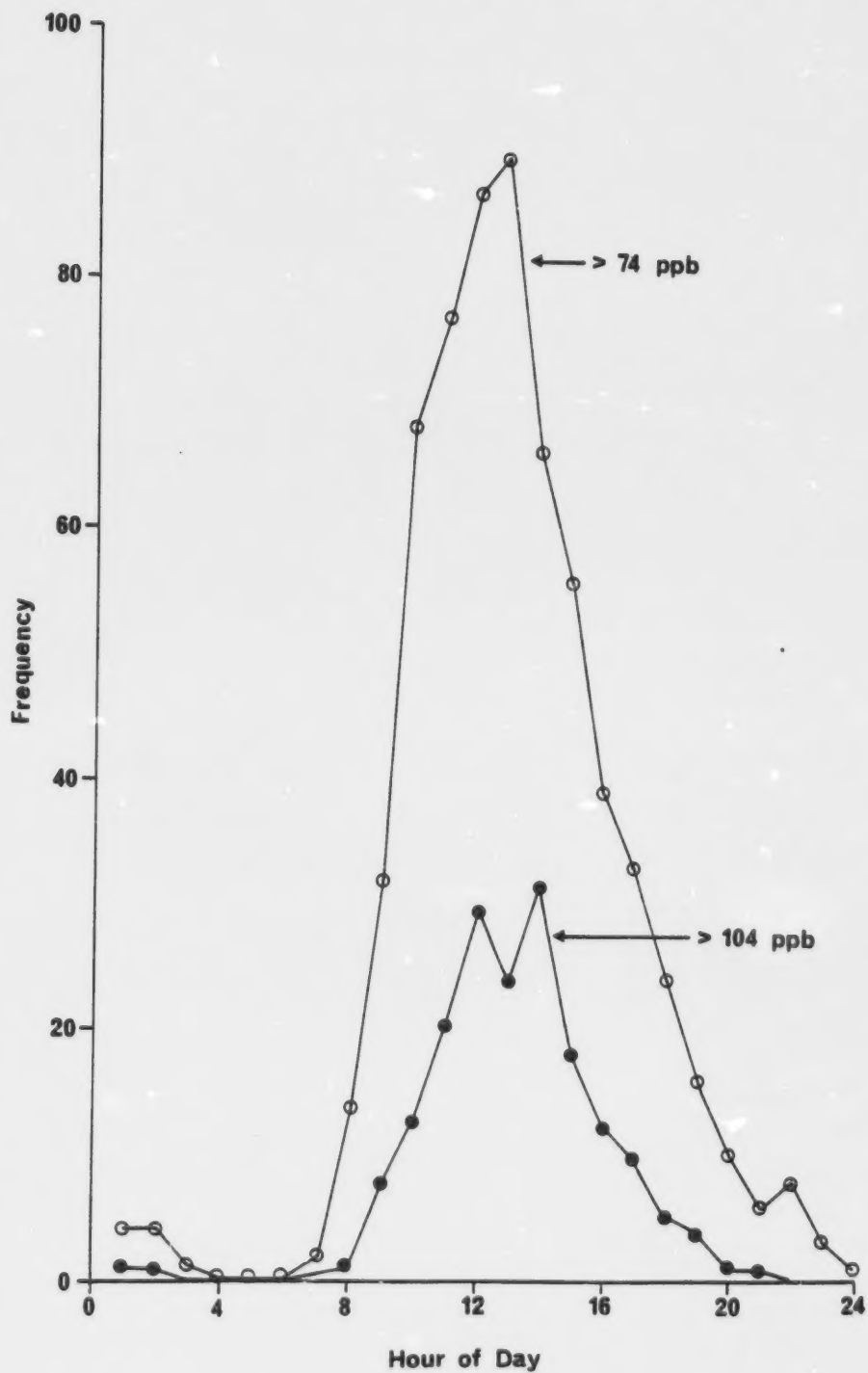


Table 3.6: Diurnal Variation of daily maximum NO_2 level for days with $\text{NO}_2 > 74$ and $\text{NO}_2 > 104$ ppb

Hr At Peak	Frequency > 74 ppb	Frequency > 104 ppb
	%	%
1	4 0.62	1 .55
2	4 0.62	1 .55
3	1 0.16	0 0
4	0 0	0 0
5	0 0	0 0
6	0 0	0 0
7	2 0.31	0 0
8	14 2.2	1 .55
9	32 5.0	8 4.4
10	68 10.6	13 7.1
11	77 12.0	21 11.5
12	87 13.6	30 16.5
13	90 14.0	24 13.2
14	66 10.3	32 17.6
15	56 8.7	18 9.9
16	39 6.1	12 6.6
17	33 5.1	10 5.5
18	24 3.7	5 2.7
19	16 2.5	4 2.2
20	10 1.6	1 0.55
21	6 0.94	1 0.55
22	8 1.2	0 0
23	3 0.47	0 0
24	1 0.16	0 0



FIGURE 3-2: DIURNAL VARIATION OF PEAK EXCEEDANCES
OF NO₂ TRIGGER CONCENTRATIONS



The factor loadings (derived from applying the Principal Axis factor method and the Varimax rotation method - see Appendix 13) are listed in Table 3.7. This table shows that high loadings for factor 1 occur for stations T7, T10, T9 and less so for T4. Similarly, for factor 2, stations T3, T2, T1 and less so T8, form another group with high loadings. For the third and fourth factors, T6 and T5, T4 respectively had high loadings.

If the spatial relationship of stations is a significant parameter in accounting for data, then groups of stations within similar locations would be described by a common factor. The stations in each of the two groups indicated for factors 1 and 2 are each in similar locations. The first group, T7, T10, T9 and less so T4 are to the east of the GVRD, while the other group of stations T3, T2, T1 and T8 are in the western section. These groupings probably also reflect the influence of other parameters - for example wind direction.

The nature of the factors that explain the high factor loadings for T6 and T5, T4 (factors 3 and 4 respectively) is not readily apparent.

This limited application of factor analysis to the data has demonstrated that spatial relationships between two groups of stations exist - and therefore similar NO_2 data may be expected for stations within each group. The earlier representative selection of stations T2 and T7 is consistent with the results from factor analysis but the justification of the selection of T4 on the basis of factor analysis is not as clearly demonstrated.



Table 3.7: Factor Analysis of Exceedance Hours:

Rotated Factor Pattern from Varimax Method

Station	Factor Loadings			
	Factor 1	Factor 2	Factor 3	Factor 4
T5	0.010	0.131	.081	0.932
T6	0.098	0.077	.874	0.173
T7	0.803	-0.113	.341	-0.008
T8	-0.465	0.590	.124	0.114
T10	0.787	-0.094	-0.280	0.156
T2	-0.099	0.801	0.262	0.107
T3	0.071	0.812	-0.210	0.348
T1	-0.050	0.810	-0.017	-0.134
T4	0.496	0.072	0.192	0.713
T9	0.708	-0.025	0.305	0.459



3.3 Episode Analysis

The numbers of hours (duration) that NO_2 levels exceeded the 104 ppb trigger level were determined to establish the duration of these occurrences. For each station on any day where there was one or more exceedance of 104 ppb, the duration was determined. These data are summarized in Table 3.8. (see also Figure 3.3). A duration of 4 hours was arbitrarily selected and therefore an episode is defined as an exceedance of the trigger concentration for four or more hours. Episodes defined in terms of three trigger levels (49, 74 and 104 ppb) were identified for each station.

The primary objective of this analysis is to identify the days on which episodes occurred and to determine the monthly and seasonal occurrences of episodes. By identifying a reasonable number of days, a representative set of meteorological conditions conducive to episode occurrence would be identified for subsequent analysis of these meteorological conditions.

Table 3.1 lists the numbers of episode days identified based on the three trigger levels. The episodes based on the 74 ppb trigger level were selected for further scrutiny since the number of episode days in the four year period was not excessive (too few episode days resulted if 104 ppb is used as the trigger concentration). Only those NO_2 episodes based on the 74 ppb trigger concentration exceeded for 4 or more hours will be considered in the following discussion.

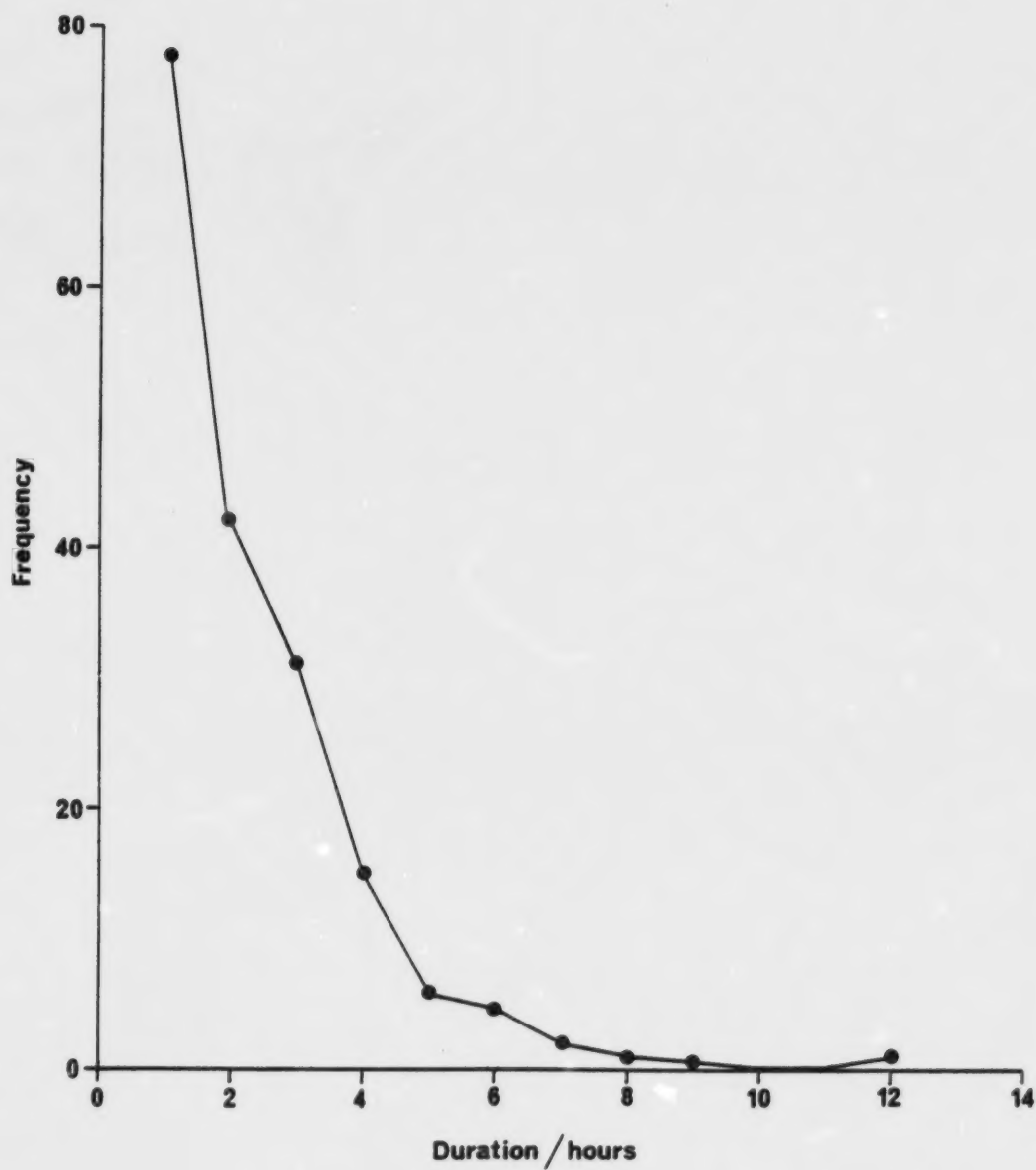


Table 3.8 Frequencies of Duration of Exceedances of 104 ppb

Duration/ hours	Frequency	Cummulative Frequency	% Frequency	Cummulative %
1	78	78	42.8	42.8
2	42	120	23.1	65.9
3	31	151	17.0	83.0
4	15	166	8.3	91.2
5	6	172	3.3	94.5
6	5	177	2.8	97.3
7	2	179	1.1	98.4
8	1	180	0.6	98.9
9	1	181	0.6	99.5
10	0	181	0	99.5
11	0	181	0	99.5
12	1	182	0.6	100



FIGURE 3-3 : FREQUENCY OF DURATION OF EXCEEDANCES OF
104 ppb



3.3.1 NO₂ Episodes by Station

The frequency distribution of episodes by station is detailed in Table 3.9. The pattern of occurrences of episodes at the various stations is similar to that for the exceedances (Section 3.2.1).

3.3.2 Temporal Variation of Episodes

The seasonal, monthly and diurnal variation of episodes are all very similar to those for the variation of the exceedances. Table 3.10 gives the frequency of station episodes by month.

The number of different days in each month for which one or more station episodes occurred and also one or more exceedance of 74 ppb occurred are listed in Table 3.11. These data are illustrated in Figure 3.4. Most exceedances of 74 ppb or episodes based on NO₂ > 74 ppb for 4 or more hours, occur in October. As was the case for exceedances of 74 ppb, December is also a month in which few (none in fact) episodes occurred.

The patterns of the monthly frequencies of episodes and exceedances all indicate that September, October, November and, to a lesser extent, January, February and March are the periods in which high NO₂ levels occur.

3.3.3 Areal Episodes

The 152 episodes (based on 4 or more hours) identified occurred on 79 different days over the 4 year period. The number of cases for



Table 3.9: Frequency of NO₂ Episodes by Station
[NO₂] > 74 ppb for 4 or More Hours

Station	Number of Episodes				
	1978	1979	1980	1981	Total
T5	1	8	7	4	20
T6	3	8	6	6	23
T7	0	14	3	2	19
T8	0	2	2	2	6
T10	7	1	5	5	18
T2	0	5	0	3	8
T3	2	1	0	1	4
T1	5	3	0	0	8
T4	4	0	4	6	14
T9	2	3	4	7	16
T1A	0	0	3	13	16
Total	24	45	34	49	152



Table 3.10: Frequency of Episodes by Month and Year

Month	Number of Episodes				
	1978	1979	1980	1981	Total
Jan	0	3	1	15	19
Feb	0	0	0	3	3
Mar	0	0	0	6	6
Apr	1	1	0	0	2
May	0	0	3	1	4
Jun	1	1	0	0	2
Jul	2	0	0	1	3
Aug	0	2	0	0	2
Sep	0	13	8	10	31
Oct	19	15	21	8	63
Nov	1	10	1	5	17
Dec	0	0	0	0	0
Total	24	45	34	49	152

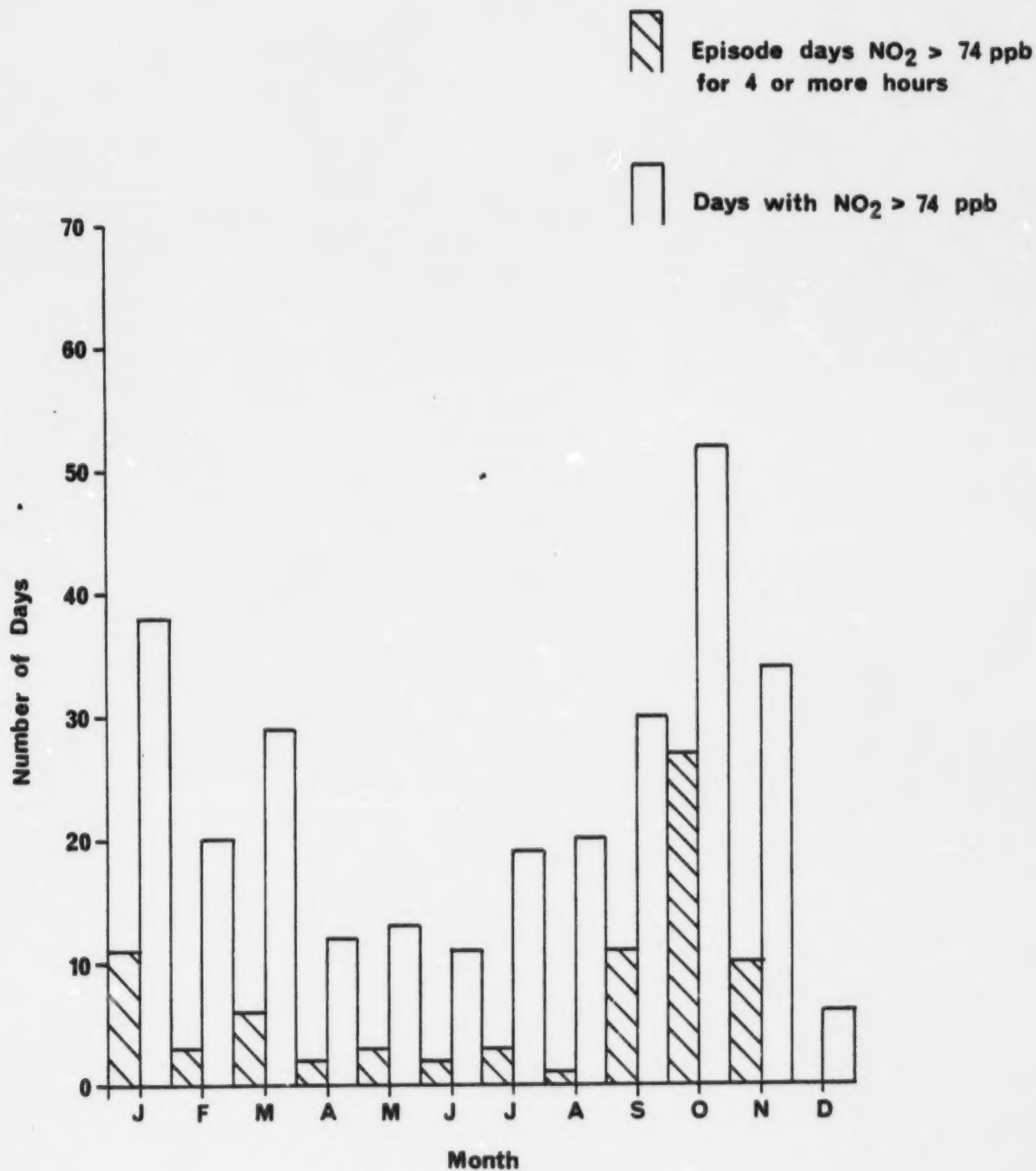


Table 3.11 Frequencies of Episode and Exceedance
Days by Month

Month	Episode Days <u>>74 ppb</u>	Exceedance Days <u>>74 ppb</u>
Jan	11	38
Feb	3	20
Mar	6	29
Apr	2	12
May	3	13
Jun	2	11
Jul	3	19
Aug	1	20
Sep	11	30
Oct	27	52
Nov	10	34
Dec	0	6
	<u>79</u>	<u>284</u>



FIGURE 3.4 : MONTHLY VARIATION OF EXCEEDANCE DAYS ($\text{NO}_2 > 74 \text{ ppb}$)
AND EPISODE DAYS ($\text{NO}_2 > 74 \text{ ppb}$ FOR 4 OR MORE HOURS)



which the episodes occurred at 1, 2 and 3 or more stations on the same day are listed in Table 3.12. Thus for example, there were 7 different days in 1979 when there were episodes at only 2 stations, and five different days in 1979 when three or more stations had episodes. The occurrence of an episode at 3 or more stations on the same day was selected as the condition to define an areal episode. During such areal episodes, it is likely that meteorological conditions would be most conducive to poor dispersion of pollutants.

Some 16 areal episodes occurred in the period 1978 - 1981. Details of these 16 cases are listed in Table 3.13.

The majority of these areal episodes occur in September* (five) and October (seven) while two each occurred in November and January.

The trios of stations at which areal episodes occur most frequently are T4, T5 and T9 followed by T4, T9 and T10, then T4, T5 and T6. These trios are all roughly colinear and therefore would be simultaneously affected by a source or sources upwind. It should be noted that factor analysis concluded that the stations T4, T9, T10 and T7 were spatially related. The areal episodes support this conclusion. It should also be noted that the other group of stations ascribed to a spatially related factor was T3, T1, T2 and T8. These stations showed few areal episodes and in general, therefore, episodes or exceedances at these stations do not occur simultaneously with those at the other group of stations. The



Table 3.12: Yearly Distribution of the Number of Station Episodes* on Different Days.

	1978	1979	1980	1981	All years
1 Station	11	12	6	18	47
2 Stations	3	7	4	2	16
3 Stations or more	1	5	4	6	16
	15	24	14	26	79

* $\text{NO}_2 > 74$ ppb for 4 or more hours.



Table 3.13: Details on Areal Episodes

NO₂ > 74 ppb for 4 or more hours

Date	Stations
06 Oct. 78	T5, T6, T10, T3, T1, T4, T9
14 Sep. 79	T5, T6, T7, T2, T3
25 Sep. 79	T5, T7, T9
10 Oct. 79	T6, T7, T2, T1
12 Oct. 79	T6, T7, T2
15 Nov. 79	T6, T8, T2
26 Sep. 80	T5, T6, T10, T4, T9
02 Oct. 80	T5, T7, T10, T4, T9
05 Oct. 80	T5, T8, T4, T1A, T9
10 Oct. 80	T5, T6, T10, T4, T9
12 Jan. 81	T7, T4, T9
14 Jan. 81	T6, T10, T9, T1A
15 Sep. 81	T5, T2, T3, T4
16 Sep. 81	T5, T6, T2, T4
23 Oct. 81	T5, T7, T8, T10
09 Nov. 81	T6, T4, T9, T1A



detailed interpretation of the spatial relationship between stations using factor analysis and areal episodes is very speculative, but the results of the limited application of the method are useful. More fruitful inferences could probably be obtained by analysis of the meteorological data (e.g. wind directions and speeds) in conjunction with the NO_2 data.



4. ESTIMATES OF PREDICTED EXCEEDANCES AND CONCENTRATIONS

Estimates of the predicted numbers of exceedances of specified NO_2 levels (e.g. the 1 hour maximum acceptable National Air Quality Objective) are extremely useful. Such estimates may be obtained by the application of statistical methods. Specifically, estimates of the following four parameters are of interest:

N_{210} = the number of hours in one year that the National Air Quality Objective maximum acceptable 1 hour concentration limit (210 ppb) is exceeded;

N_{105} = the number of hours in one year that the 105 ppb level is exceeded;

N_{75} = the number of hours in one year that the 75 ppb level is exceeded;

$x_{0.01}$ = the hourly (NO_2) value which will be exceeded 0.01 % of the time (about one hour per year).

In obtaining these four estimates from the measured time series of hourly NO_2 concentrations, two assumptions are implied. Firstly, the series itself must be considered a set of random variables. This assumption is reasonable (Georgopoulous and Senfeld (1980)) given that air pollutant concentrations are inherently random because of their dependence



on fluctuating source parameters and meteorological conditions. However, the observed temporal patterns in air quality data (diurnal and seasonal variations for example) imply that pollutant concentrations are not completely random or independent. The second assumption is that the population's probability distribution is assumed to conform to a theoretical distribution defined by a mathematical function.

The satisfactory agreement between observed air quality data and a theoretical distribution function is indication that the two assumptions are reasonable. Thus statistical inferences may be made although the assumption of independence of air pollution data is not strictly valid.

The first step in analysing the data was to determine which, if any, theoretical distribution function suitably describes the data. A sample of the data (one year's data from each of four stations) was fitted graphically to each of two distribution functions, namely the lognormal and the Wiebull distribution functions. The subsequent analysis involved application of two methods - the quantile method and the maximum likelihood method - for calculating the parameters of interest. These calculations are based on the distribution function (the lognormal) that best describes the data. The parameters of interest - N_{210} , N_{105} , N_{75} and $x_{.01}$ - are then compared with corresponding historical observed values.

4.1 Preliminary Analysis

Air pollution data commonly exhibit distribution shapes resembling



the lognormal or Weibull distribution functions. For simplicity these functions are adopted in their two parameter form. The conformity of the data to these functions was assessed from actual distribution plots of one year's data from each of four stations on grid systems linearized for each of the two theoretical distributions.

The lognormal plots were more linear than those for the Weibull function hence the data conformed better to the lognormal distribution. The Weibull function deviated significantly from the actual distribution especially for the high percentiles. On this basis, the lognormal distribution function was employed in the subsequent analysis. This analysis involved employing two methods - the quantile method and the maximum likelihood method - for estimating parameters of interest.

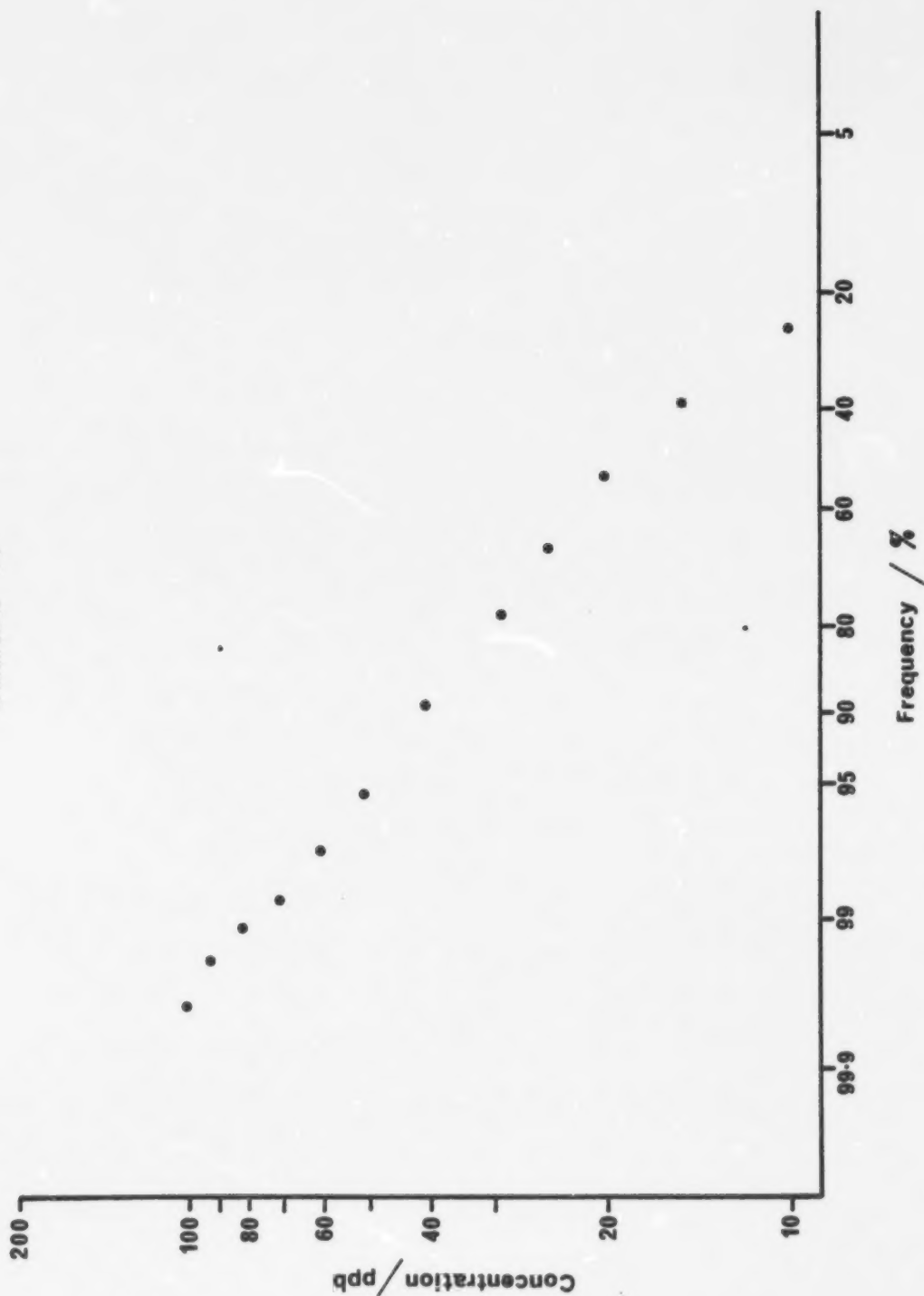
4.2 Lognormal Distribution Analysis

All the available data for the 1978 - 1981 period from each station were analyzed to determine the lognormal distributions of the hourly data and also for the daily maximum values. A typical lognormal frequency distribution plot is shown in Figure 4.1 in which data from station T5 are plotted. A brief summary of the relevant equations and methods for calculating the number of hours per year of exceedances of specified levels and the maximum hourly concentrations per year are given in Appendix 14.



FIGURE 4-1 : 1 HOUR AVERAGE NO₂ CONCENTRATION DISTRIBUTIONS 1978 - 1981

STATION T5



4.3 Determination of Estimates of Numbers of Exceedances

4.3.1 Quantile Method

This method is merely an extrapolation based on measured quantiles, assuming a lognormal extension of the distribution. As such, it is dependent on the sample size and the two percentiles chosen. The 90th and 99th percentiles were selected because of their proximity to the regions of interest and also because the sample populations at these percentiles were still large.

The extrapolation - to the point where the straight line (joining the 90th and 99th percentiles) crosses the concentration of interest - is performed by calculation. The slope and intercept of the line are first estimated and appropriate substitutions in this equation are then made. Details of the equations used are given in Appendix 14.

The estimation of the hourly concentration which will be exceeded once per year ($x_{.01}$) is obtained by extrapolation to the 99.9 % level and determining the concentration at that point. (See Appendix 14 for equations.)

The estimates of N_{210} , N_{105} , N_{75} and $x_{.01}$ obtained using the quantile method are detailed in Table 4.1.

4.3.2 Maximum Likelihood Method

In contrast to the quantile method where two points in the



distribution were used to parameterize the linearized lognormal distribution function, estimates of the straight line parameters were obtained by calculating the values of these parameters using all the available data. The parameters required are the geometric mean and standard deviation. Similar extrapolations are made to obtain the N_x and $x_{.01}$ values, and these estimates are tabulated in Table 4.1. Details of the equations used are summarized in Appendix 14.

4.4 Results and Comparison of Methods

Table 4.1 shows estimates of $x_{.01}$ and N_{210} , N_{105} and N_{75} calculated by the quantile (Q) and maximum likelihood (ML) methods. Also indicated in Table 4.1 are average values, over the 4 year period, of the observed numbers of exceedances of 210, 104 and 74 ppb. The estimates of $x_{.01}$ can be compared either with the average of the annual maximum 1 hour values for the four year period or with annual maximum for individual years. Such comparisons are indicated in Table 4.2.

The estimated number of hours per year that the 1 hour national air quality objective is exceeded, i.e. N_{210} , is less than one at all stations except T7 when the quantile method is used. It is not meaningful to apply the calculation to time periods of less than one hour because the population consists of a time series of one hour averages that must be treated as indivisible, discrete units. Hence, the less than one (< 1) implies that no exceedance will occur in a given year.



Table 4.1

Calculated Concentrations likely to be Exceeded 0.01% of Hours Each Year
and Comparison of Observed and Calculated Hours of Exceedances

Station	x _{.01}		N ₂₁₀			N ₁₀₅			N ₇₅		
	Q	ML	Obs.#	Q	ML	Obs.#	Q	ML	Obs.#	Q	ML
T5	190	297	0	<1	5	16	27	82	71	103	248
T6	208	310	0	<1	5	19	30	78	78	118	223
T7	226	259	*	1	3	15	25	39	50	84	124
T8	150	219	0	<1	<1	5	7	32	26	38	120
T10	163	427	0	<1	14	7	13	121	37	78	291
T2	106	171	0	<1	<1	4	<1	18	23	16	102
T3	107	200	0	<1	<1	2	<1	32	16	18	145
T1	154	199	0	<1	<1	8	16	47	43	116	234
T4	148	196	0	<1	<1	9	8	28	42	52	122
T9	182	252	0	<1	3	10	17	48	45	74	156
T1A	172	197	0	<1	<1	11	25	50	58	154	254

Average annual number of exceedances 1978 - 1981

* 1 Exceedance observed during 1978 - 1981

x_{.01} Concentration expected to be exceeded 0.01 percent of the hours in 1 year i.e., 1 hour each year (ppb).

N_x Expected number of hours each year that this concentration x is likely to be exceeded.

Q Quantile Method

ML Maximum Likelihood Method



Table 4.2

Comparisons of Estimates of $x_{.01}$ With Historical Data

Station	Estimated*		Observed*				
	$x_{.01}$						
	<u>Q</u>	<u>ML</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>1981</u>	<u>Average</u>
T5	190	297	166	198	157	180	175
T6	208	310	133	179	185	158	164
T7	226	259	93	245	174	155	187
T8	150	219	117	178	111	119	131
T10	163	427	146	138	166	182	158
T2	106	171	97	161	180	150	147
T3	107	200	128	89	105	110	108
T1	154	199	210	153	89	-	151
T4	148	196	177	161	142	188	167
T9	182	252	156	164	156	150	157
T1A	172	197	-	-	160	194	177

* Concentration in ppb.



Estimates of N_x by the maximum likelihood method are consistently higher than the corresponding value calculated by the quantile method. The analogous situation exists when the estimates of $x_{.01}$ by the two methods are compared.

The quantile method estimates of N_x , when compared with historical data, show good agreement. Note that the observed values of N_x in Table 4.1 are the average values over the four year period. The quantile method estimates are generally greater than the observed. Of course estimates of N_x by the maximum likelihood method are always considerably higher than the corresponding observed values.

When the estimated and observed $x_{.01}$ values are compared (Table 4.2) a similar picture emerges. The agreement between observed values (for individual years or for the average over the four year period) and those calculated by the quantile method is very good, while poor agreement is obtained for the maximum likelihood method estimates.

Clearly the better agreement shown by the quantile method indicates that the data deviates from lognormal distribution at the high concentration end and estimates based on extrapolations from nearby percentiles are likely to be more reliable. The deviation from lognormality is likely to be due to the non-random nature of the hourly data.

In view of this, the data for the maximum daily values from each station in the 4 year period were fitted to the lognormal distribution. These data are more likely to be random.



The estimates $x_{.27}$, N_{210} , N_{105} and N_{75} together with the mean observed values of related parameters are given in Table 4.3. The $x_{.27}$ concentration represents the daily maximum that will be exceeded .27 % of the time or once per year. Since there are 365 days each year, then $1/365 \times 100\%$ is 0.27 %. The values calculated for $x_{.27}$ are all lower than the 210 ppb the National Air Quality maximum acceptable standard for a one hour average. When compared with the highest observed daily maximum values, the $x_{.27}$ values calculated by both methods are lower - with one exception (station T9 by the Quantile method).

The agreement between the $x_{.27}$ and N_x values calculated by the two methods is good. This indicates that the lognormal distribution is satisfied even at the higher percentiles (unlike the case for the distribution of hourly data).

When the estimates are compared with observed values, the estimated values of N_x are lower than the observed values for $x = 105$ and 75 ppb, but good agreement is shown for $x = 210$ ppb. In the case of comparisons for $x_{.27}$, the agreement is good (the mean of the highest daily maximum values each year are listed in Table 4.3). Comparisons with $x_{\max}$ for individual years can also be made by inspecting the $x_{.01}$ data of Table 4.2 since the observed values $x_{.27}$ and $x_{.01}$ are the same.).

It should be noted that when comparing the N_x values with the observed numbers of exceedances, the latter include all hours for which 104 ppb were exceeded and not just all cases where the daily maximum exceeded 104 ppb. This will result in a larger number of observed exceedances



Table 4.3

Comparison of Observed and Calculated Hours of Exceedances (based on lognormal distribution of daily maximum values)

Station	mean $x_{\max}$ ppb	$x_{.27}$ /ppb		N_{210}			N_{105}			N_{75}		
		Q	ML	Obs	Q	ML	Obs	Q	ML	Obs	Q	ML
T5	175	188	156	0	<1	<1	16	12	8	71	34	33
T6	164	179	169	0	<1	<1	19	12	10	78	37	37
T7	167	178	160	*	<1	<1	15	10	10	50	27	29
T8	131	160	99	0	<1	<1	5	5	<1	26	16	7
T10	158	162	149	0	<1	<1	7	7	6	37	23	26
T2	147	130	97	0	<1	<1	4	3	<1	23	12	7
T3	108	97	104	0	<1	<1	2	<1	1	16	7	10
T1	151	150	145	0	<1	<1	8	8	7	43	36	35
T4	167	158	132	0	<1	<1	9	6	4	42	21	19
T9	157	178	145	0	<1	<1	10	8	5	45	25	21
T1A	177	193	140	0	<1	<1	11	12	7	58	35	37

* 1 Exceedance observed

Q Quantile

ML Maximum Likelihood

N_x Expected number of hours each year that the concentration x is likely to be exceeded

Obs Average number of exceedances observed.

than are estimated (especially when comparing the 75 ppb level).

The analysis of the data indicates that the lognormal distribution is more closely followed for the daily maximum population than for the data for all hours.

In summary, the statistical analysis of the NO_2 data has indicated the following:

1. The data for the hourly NO_2 values at each station have been described by a two parameter lognormal distribution equation.
2. Two approaches, the quantile method and the maximum likelihood method, were used to predict the numbers of hours that specified levels x , are likely to be exceeded (namely N_{210} , N_{105} and N_{75}), and to predict the concentration likely to occur 0.01 % of the time each year, i.e. $x_{.01}$ or the annual maximum one hour value.

The quantile method (based on the linear extrapolation of the 90th and 99th percentiles) more accurately predicts the quantities $x_{.01}$, N_{210} , N_{105} and N_{75} as assessed by comparisons with observed values.

The better reliability of the quantile method indicates that deviation from a lognormal distribution occurs at higher concentrations.

3. The daily maximum values were also described by a two parameter



lognormal distribution equation. The close agreement between the quantile method and the maximum likelihood method in predicting $x_{.27}$ and N_x values indicate that the daily maximum values more closely follow the lognormal distribution than the hourly values.

The daily maximum NO_2 levels are more likely to be independent or randomly distributed than hourly data which show consistent diurnal patterns. The daily maximum NO_2 data should therefore better satisfy the requirements for the application of statistical methods.

4. Estimates of $x_{.27}$ from daily maximum data, indicate that all stations will comply with the maximum acceptable 1 hour air quality objective for NO_2 .



5. SUMMARY AND CONCLUSIONS

Air quality data for the nitrogen oxides (NO , NO_2 and NO_x) from the GVRD network over the period 1978 to 1981 were analysed. The compliance with the national air quality objectives was assessed and the temporal and spatial trends in the data were evaluated. Nitrogen dioxide exceedances (of selected trigger concentrations) and episodes (exceedances of specified concentrations for four or more hours) were identified. The temporal and spatial variation of exceedances and episodes were determined. Estimates of the yearly maximum one hour NO_2 concentration at each station were made based on the statistical analysis of the available one hour average and daily maximum data.

Over the four year period there was only one occasion on which the national air quality maximum acceptable 1 hour average NO_2 objective of 210 ppb ($400 \mu\text{g m}^{-3}$) was exceeded. One exceedance of the 24 hour maximum acceptable 24 hour average objective occurred during the four year period.

Temporal patterns in the data revealed no discernable increase or decrease in the annual mean concentrations for NO_2 , NO or NO_x over the four year period. Monthly means of NO , NO_2 and NO_x levels during the months October to December and January to March, were higher than for the rest of the year. The diurnal patterns for NO and NO_x are similar and are typified by two peaks each day at times corresponding to expected contributions from morning (~1000 hours) and afternoon (~2000 hours) traffic.



NO₂ levels peaked most frequently at 1400 hours as is consistent with the requirements for conversion of NO to NO₂.

The available data over the four year period showed that the number of NO₂ exceedances (of 104, 74 and 49 ppb) was greatest for station T6 followed by T5 and T7. Station T3 had the least number of exceedances. An unusually large number of exceedances of 104 and 74 ppb occurred at station T1A in 1981. Differences in the extents of data recovery at the various stations preclude more definitive ranking of the frequencies of exceedances at the various stations.

Most exceedances occurred in October, and there were unusually few in December (since both November and January had relatively large numbers of exceedances). The monthly variation of episodes is similar to that for exceedances.

Areal episodes (episodes at 3 or more stations) occurred most often in September - November (14 cases) but also occurred in January (2 cases). Two trios of stations at which areal episodes occur most frequently are roughly colinear and indicate these stations are downwind of sources.

Factor analysis of data for hours when NO₂ exceeded 74 ppb indicated two spatially related factors were important in describing the data. The stations T9, T7 and T10 are most closely related by one factor, while T1, T2, T3 and T8 are related by the second factor. The stations in each group are in similar locations and therefore are spatially related. The spatial



relationships identified by factor analysis are consistent with the occurrence of areal episodes. More specific relationships between the NO_2 levels at various stations and the sources of NO_x can not be formulated because of the multiplicity of sources and the complexity of the terrain.

Statistical methods were utilized to obtain estimates of the annual maximum one hour concentration and the number of hours each year that specified concentration levels x , are likely to be exceeded (N_x), for each station. The population of daily maximum 1 hour NO_2 levels was considered to be more random and independent hence are more suitable for the application of statistical methods. Estimates of the highest daily maximum 1 hour NO_2 level, $x_{.27}$, indicate that all stations are likely to be in compliance with the national air quality maximum acceptable 1 hour objective of 210 ppb.



Appendix 1
ANNUAL SUMMARY FOR NITROGEN DIOXIDE /PARAN-203/
ALL CONCENTRATIONS IN PPM

STATION ADDRESS	N_DAYS	CBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1MP	MAX_24HR	N_ACCINN	N_ACC24H
000005 CONFLDERATION P	233	64	8	13	19	26	33	49	28	166	68	0	0
000006 GOND HEACH WUMKS	273	75	9	13	18	24	30	51	19	133	55	0	0
000007 ANRUME ELEM SCH	137	38	2	6	7	11	14	22	8	93	24	0	0
000008 LIONS GATE SIP	393	83	9	13	17	23	27	44	18	117	48	0	0
000010 DEP. OF HIGHWAYS	30	8	12	17	26	41	46	52	27	146	52	0	0
0100106 G.V.H.D. OFFICE	366	84	13	17	23	29	35	42	24	97	45	0	0
0100108 MANITOBA WUMKS V	299	62	17	21	26	31	36	42	27	128	64	0	0
0100109 B.C. HYDRU PARK	113	31	15	21	31	46	59	111	34	210	116	0	1
0100110 KENSINGTON PARK	332	91	16	20	24	38	37	50	25	177	62	0	0
0100111 HOCKY POINT PARK	282	77	8	11	18	24	30	48	19	156	60	0	0



Appendix 2
ANNUAL SUMMARY FOR NITROGEN DIOXIDE /PARAM-203/
ALL CONCENTRATIONS IN PPM

STATION ADDRESS	N_DAYS	OBS.	PERC	PER_10	PER_12	PER_25	PER_50	PER_75	PER_90	PER_99	ANNUAL MEAN	MAX_1HR	MAX_24HR	N_ACC1HR	N_ACC24H
0000005 CONFEDERATION P	308	84		9	12	20	29	39	59	22	100	75	0	0	0
0000006 GVRD BEACH WORKS	253	60		8	11	16	23	31	59	18	179	59	0	0	0
0000007 ANNOHE ELLH SCH	234	64		7	10	15	22	34	64	18	245	86	1	0	0
0000008 LIONS GATE STP	348	95		10	14	18	22	29	47	19	178	50	0	0	0
0000010 DEP. OF HIGHWAYS	149	41		10	14	18	25	33	56	20	138	59	0	0	0
0100106 G.V.R.D. OFFICE	363	83		14	19	23	28	34	57	24	101	67	0	0	0
0100109 MANITABA WORKS V	278	76		13	18	23	28	36	49	24	89	60	0	0	0
0100109 B.C. HYDRO PARK	324	80		16	21	28	35	44	69	29	183	76	0	0	0
0100110 KENSINGTON PARK	213	58		5	9	16	23	28	47	16	161	52	0	0	0
0100111 RUCKY POINT PARK	161	44		5	8	12	22	31	65	16	164	69	0	0	0



Appendix 3

ANNUAL SUMMARY FOR NITROGEN DIOXIDE /PARAM-203/

ALL CONCENTRATIONS IN PPM

STATION ADDRESS	N_DAYS	OBS	PERC	YEAR=1980												MAX_1HR	MEAN	MAX_24HR	N_ACC1HR	N_ACC24H
				PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_	MEAN	MAX_1HR	MAX_24HR	N_ACC1HR	N_ACC24H					
0000005 CONFEDERATION P	317	87	10	14	20	27	39	62	22	157	8.0	0	0	0	0					
0000006 GVRD BEACH WORKS	250	76	11	15	21	28	37	56	22	185	6.8	0	0	0	0					
0000007 AMORE ELEM SCH	321	88	11	15	19	23	29	44	20	174	7.6	0	0	0	0					
0000008 LIONS GATE STP	308	84	12	15	19	23	26	38	19	111	4.6	0	0	0	0					
0000010 DEP. OF HIGHWAYS	350	96	7	12	16	22	28	46	17	166	5.4	0	0	0	0					
0100105 C.V.R.D. OFFICE	361	99	13	17	22	26	31	40	22	180	3.4	0	0	0	0					
0100109 MANITONA WORKS Y	311	85	8	12	18	25	33	45	19	105	1.6	0	0	0	0					
0100109 B.C. HYDRO PARK	84	23	23	24	27	31	37	47	28	89	4.7	0	0	0	0					
0100110 KENSINGTON PARK	323	88	18	17	21	26	32	52	22	142	5.0	0	0	0	0					
0100111 ROCKY POINT PARK	90	27	12	15	21	26	39	53	23	156	5.3	0	0	0	0					
0100112 B.C. HYDRO PARK	252	69	14	21	28	36	44	56	29	160	7.0	0	0	0	0					



Appendix 4

ANNUAL SUMMARY FOR NITROGEN DIOXIDE /PARAM-203/
ALL CONCENTRATIONS IN PPM

STATION ADDRESS	N_DAYS	CMS_PRC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	ANN_MEAN	MAX_1HR	MAX_24HR	N_ACC20+
000005 CONFEDERATION P	199	55	14	17	23	29	41	61	25	100	56	0
000006 CWRD REACH WORKS	223	61	11	13	20	27	37	65	22	158	78	0
000007 A-MORE ELEM SCH	255	70	6	9	15	21	29	42	16	155	64	0
000008 LIONS GATE STP	14	4	29	34	42	49	61	67	42	119	57	0
000010 DEP. OF HIGHWAYS	207	57	5	10	16	24	32	64	18	182	79	0
010010 G.V.R.D. OFFICE	288	79	14	19	24	29	36	47	24	150	59	0
010010 J. MANITOBA WILKS Y	173	47	13	17	21	27	34	47	23	110	68	0
010010 KENNINGTON PARK	276	76	13	16	20	27	35	55	23	188	64	0
010011 ROCKY POINT PARK	319	87	10	14	18	26	34	49	21	150	51	0
010012 B.C. HYDRO PARK	320	88	21	25	30	36	49	78	33	104	98	0
0310173 CHILLIWACK A	4	1	1	1	2	2	3	3	2	25	3	0
1100030 ARNOTSFORD A	27	7	7	10	15	18	20	22	14	41	22	0



Appendix 5

SEASONAL SUMMARY REPORT FOR NITROGEN DIOXIDE /PARAM=203/

ALL CONCENTRATIONS IN PPB

STATION ADDRESS	N_DAYS	CBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	SSM_NEAM	MAX_1P	MAX_24HR	N_ACCINR	N_ACC24P	SEASON= WINTER																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																



Appendix 6

SEASONAL SUMMARY REPORT FOR NITROGEN DIOXIDE /PARAM=203/

ALL CONCENTRATIONS IN PPB

SEASON=SPRING

STATION ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	SSN_MEAN	MAX_1HR	MAX_24HR	N_ACC1HR	N_ACC24H
0000005 CONFEDERATION P	269	74	8	11	15	20	26	41	16	89	67	0	0
0000006 GARD BEACH WORKS	259	71	9	13	17	24	30	54	19	133	58	0	0
0000007 ARMOHE ELEM SCH	278	76	4	9	14	19	24	41	14	120	54	0	0
0000008 LIONS GATE STP	234	64	7	10	15	16	24	30	15	120	44	0	0
0000010 DEP. OF HIGHWAYS	179	49	4	8	15	21	26	59	15	182	64	0	0
0100106 J.V.N.O. OFFICE	336	92	14	18	23	28	34	43	23	100	57	0	0
0100107 MANITOBA WORKS Y	274	75	11	15	20	25	31	44	21	97	67	0	0
0100109 H.C. HYDRO PARK	117	32	17	23	29	36	43	70	30	153	74	0	0
0100110 KENSINGTON PARK	284	78	6	13	20	27	34	50	20	100	53	0	0
0100111 ROCKY POINT PARK	212	58	6	9	13	17	23	47	14	145	68	0	0
0100112 D.C. HYDRO PARK	161	44	23	28	35	41	47	62	34	103	70	0	0

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Appendix 7

SEASONAL SUMMARY REPORT FOR NITROGEN DIOXIDE /PADAM=203/

ALL CONCENTRATIONS IN PPB

----- SEASON=SUMMER -----

STATION ADDRESS	N_DAYS	CBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	SSM_NEAN	MAX_1HR	MAX_24HR	N_ACC1HR	N_ACC24H
0000005 CONFEDERATION P	312	85	10	14	20	26	38	61	22	180	9	0
0000006 GARD BEACH WORKS	318	86	10	14	20	27	35	56	21	164	8	0
0000007 ANNIE ELEA SCH	239	65	8	12	17	21	27	50	18	175	8	0
0000008 LIONS GATE STP	269	73	9	12	16	20	24	34	16	105	0	0
0000010 DEPT. OF HIGHWAYS	188	51	9	14	20	28	34	53	21	166	0	0
0100106 G.V.P.D. OFFICE	327	89	13	17	22	28	33	51	23	161	0	0
0100109 NANTUBA WORKS Y	325	88	10	13	19	25	30	46	20	110	0	0
0100109 U.C. HYDRO PARK	153	42	13	17	23	30	37	47	24	101	0	0
0100110 KENSINGTON PARK	246	67	13	16	21	27	38	55	23	188	0	0
0100111 ROCKY POINT PARK	215	58	10	14	19	27	35	60	22	164	0	0
0100112 D.C. HYDRO PARK	182	49	14	18	25	31	36	58	25	151	0	0



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Appendix 8

SEASONAL SUMMARY REPORT FOR NITROGEN DIOXIDE /PARAM-203/
ALL CONCENTRATIONS IN PPB

STATION ADDRESS	N_DAYS	CES_PERC	SEASON=ALL										
			PER_10	PER_25	PER_50	PER_75	PER_90	PER_99	SSM	MEAN	MAX_1PR	MAX_20PR	N_ACCINN
0000005 CONFEDERATION P	257	93	12	16	23	31	41	70	25	100	75	0	0
0000006 GVRD REACH WORKS	192	70	11	14	19	25	35	50	21	105	59	0	0
0000007 ANNOME ELEM SCH	172	62	8	13	19	26	34	79	21	245	96	1	0
0000008 LIONS GATE SIP	190	72	14	17	21	24	30	45	22	130	50	0	0
0000010 DEP. OF HIGHWAYS	183	66	0	12	16	20	27	53	17	146	59	0	0
0100106 G.V.H.O. OFFICE	264	96	13	17	22	27	33	54	23	180	57	0	0
0100108 MANITORA WORKS V	187	68	20	25	30	36	42	63	31	120	54	0	0
0100109 B.C. HYDRO PARK	67	24	16	20	27	30	60	116	32	210	116	0	1
0100110 KENSINGTON PARK	223	81	15	10	21	26	30	50	22	177	52	0	0
0100111 RUCKY POINT PARK	130	47	7	14	21	26	34	62	21	156	53	0	0
0100112 U.C. HYDRO PARK	88	32	18	23	28	33	30	54	20	160	54	0	0



Appendix 9

ANNUAL SUMMARY FOR NITRIC OXIDE /PARAN=202/

ALL CONCENTRATIONS IN PPB

STATION	ADDRESS	N_DAYS	OBS_PRC	PER_10	PER_25	PER_50	PER_75	PER_90	ANN_MEAN	MAX_1HR	MAX_24HR
000005	CONFEDERATION P	318	85	6	10	16	38	149	27	455	195
000006	GYRD BEACH WORKS	251	89	19	24	32	40	97	26	254	110
000007	ANDRE ELEM SCH	312	84	1	2	4	8	47	6	118	51
000008	LIONS GATE STP	297	81	9	10	24	39	115	32	375	126
000010	DLP. 4P HIGHWAYS	330	81	13	20	33	63	174	48	632	260
010010	S.V.B.D. OFFICE	304	97	17	23	39	71	235	55	713	306
010010	MANITIBA WORKS V	281	77	0	13	25	54	211	43	861	266
010010	U-C. HYDRO PARK	94	20	31	48	65	80	274	75	694	274
010010	KENSINGTON PARK	313	81	10	14	22	37	144	31	560	163
010011	ROCKY POINT PARK	86	26	16	24	42	70	221	49	277	221
010012	B-C. HYDRO PARK	234	64	30	47	64	90	247	70	725	278

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Appendix 10

ANNUAL SUMMARY FOR NITRIC OXIDE /PARADP=202/

ALL CONCENTRATIONS IN PPB

STATION	ADVERSE	N_DAYS	OBS_PERC	YEAR=1981										MAX_1MR	MAX_2MR
				PER_10	PER_25	PER_50	PER_75	PER_90	PER_95	ANNUAL_MEAN					
000001	CONFIRMATION P	177	48	6	9	15	25	72	231	31	493	245			
000006	GYM REACH WORKS	189	55	13	20	33	44	68	180	39	432	138			
000007	AMMUNITION FLEM SCH	217	59	1	0	0	11	14	53	9	159	55			
000008	LIONS GATE STP	17	5	11	21	47	69	110	118	34	283	118			
000010	DEP. OF HIGHWAYS	177	48	0	15	24	37	115	248	67	1000	276			
000016	S.V.R.D. OFFICE	293	67	17	23	37	65	125	348	50	874	350			
000018	MANITOWA WORKS Y	137	30	15	20	43	68	178	534	74	703	244			
000019	KELTIMETON PARK	264	67	0	12	21	67	134	746	57	879	280			
000011	ROCKY POINT PARK	279	76	12	10	20	60	104	255	44	448	253			
000012	B.C. HYDRO PARK	200	77	30	0.2	75	110	191	384	97	844	556			



Appendix 11

ANNUAL SUMMARY FOR TOTAL NITROGEN OXIDES /PARAM-204/

ALL CONCENTRATIONS IN PPB

STATION	ADDRESS	N_DAYS	OBS_PERC	PER_10	PER_25	PER_50	PER_75	PER_90	PER_95	ANN_MEAN	MAX_1HR	MAX_24HR
000005	CONFEDERATION P	310	85	20	27	38	57	106	201	50	495	258
000006	GRIND HEACH WORKS	250	60	34	41	54	70	96	147	59	327	155
000007	ARMORE ELEM SCH	315	86	16	20	25	32	40	85	27	189	92
000008	LUMAS GATE STP	298	81	25	33	43	62	92	140	51	395	156
000010	DEP. OF HIGHWAYS	333	91	25	30	54	84	129	190	66	657	301
010010	G.V.H.D. OFFICE	324	97	35	43	62	95	143	272	77	762	327
010010B	MANITOWA WORKS V	282	70	18	28	41	71	123	233	58	905	296
010010Y	B.C. INDRU PARK	94	26	56	74	94	120	160	316	136	781	316
0100110	KENNINGTON PARK	312	85	27	34	46	62	95	184	54	595	291
0100111	ROCKY POINT PARK	97	27	32	42	64	100	120	227	73	306	227
0100112	B.C. HYDRO PARK	203	55	58	72	97	132	181	295	110	741	321



Appendix 12

ANNUAL SUMMARY FOR TOTAL NITROGEN OXIDES /PARAM-200/

ALL CONCENTRATIONS IN PPB

STATION	ADDRESS	N_DAYS	OBS_PERC	YEAR=1981								ANN_MEAN	MAX_1HR	MAX_24HR
				PER_10	PER_25	PER_50	PER_75	PER_90	PER_99					
0000005	CUMFEDENATION P	177	48	21	26	41	65	110	201	36	577	345		
0000006	GVND BEACH WORKS	195	55	26	37	56	73	104	241	52	525	248		
0000007	ANDORE ELEN SCH	218	60	11	15	24	34	43	83	24	222	91		
0000008	LIONS GATE STP	14	4	47	67	89	110	149	163	32	375	163		
0000010	DEP. OF HIGHWAYS	176	48	15	28	43	77	140	278	54	507	317		
0100106	G.V.N.D. OFFICE	243	67	36	47	65	92	153	381	82	877	427		
0100108	MANITIBA WORKS Y	141	39	25	38	61	111	185	543	31	798	656		
0100110	KENSINGTON PARK	241	64	23	30	45	74	176	758	31	990	783		
0100111	RUCKY POINT PARK	279	76	25	33	51	77	137	246	66	508	297		
0100112	H.C. HYDRO PARK	280	77	63	80	108	152	233	410	130	837	606		



Appendix 13

Factor Analysis

Brief Description

Factor analysis seeks to resolve a set of variables linearly into a smaller number of categories or factors. The correlations among the variables are first determined and this yields a matrix of correlation coefficients. This matrix is then analysed by one of several available techniques to yield a solution in which a smaller number of common factors (than variables) are identified. These factors will convey all the essential information of the original set of variables.

In the present context the variables used are the available NO_2 concentrations in excess of 74 ppb at each of the 10 GVRD stations throughout the period 1978 - 1982. Correlation coefficients among all possible pairs of stations were calculated and the matrix of correlations (a 10 x 10 matrix) is given in Table A13.1.

Thus for each of the j stations ($j = 10$) there were i values ($i = 1135$ hours for which data were available).

If the NO_2 concentration at any station for the i th hour is designated z_{ji} then the correlation coefficients between NO_2 levels at pairs of stations z_j, z_k are given by r_{jk} .



Further analysis of the correlation matrix can be performed by several techniques. The basic factor analysis model attempts to describe the variables z_j (the NO_2 concentrations at each station) by a smaller number (m) of factors, F_m , and a unique factor, Y , such that we can write:

$$z_j = a_{j1} F_1 + a_{j2} F_2 + a_{j3} F_3 + \dots a_{jm} F_m + u_j Y_j \quad (13.1)$$

The m factors are the same for each of the j variables but the linear equation relating the variables to the Factors (F_m) have different constants a_{jm} associated with each factor. The coefficients a_{jm} are termed the factor loadings. The factor analysis model (equation 13.1) is designed to maximally reproduce the correlation matrix.

The process of obtaining the factor loadings from the correlation matrix involves firstly replacing the diagonal elements of the correlation matrix (normally a value of unity) with estimates of the amount of variance that is within the common factor space. Next the matrix is diagonalized. In this process a set of j eigen values are found. These eigen values essentially indicate the error content of the data by the corresponding eigen vectors. In practice a selected, convenient number of these eigen vectors are retained - the number selected is such that most of the total variance in the data is accounted for.

In the present example, the first 4 eigen values accounted for 76.4 % of the variance. An arbitrary choice of the 4 eigen values and hence



factors were retained for further analysis. The factor loadings for each variable (the NO_2 concentration in this instance) are then derived and are tabulated as a factor pattern. A rotated factor pattern using the Varimax method was obtained. The details of intermediate and final results of the factor analysis are summarized in Tables A13.1 and A13.2.

Variables with similar large values of a particular factor are therefore associated. In the present example, stations T7, T10, T9 and less so T4 have large factor loadings for Factor 1. Similarly, stations T3, T1, T2 and less so T8 have large factor loadings for Factor 2.

These groups of stations are therefore each associated with a common factor. Since the objective is to determine if there are geographic or spatial relationships between stations, these two groups should be examined to test this. In fact stations in each of these groups are in similar locations and it may be therefore presumed that Factors 1 and 2 are geographic factors.



TABLE A18.1

Factor Analysis of Exceedance Hours: Correlation Coefficient Matrix

CORRELATION COEFFICIENTS / PRUM > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS											
STN005	STN006	STN007	STN008	STN009	STN010	STN011	STN012	STN013	STN014	STN015	STN016
1.00000 0.00000 778	0.2677 0.0000 591	0.0332 0.0000 454	0.1914 0.0000 562	0.1170 0.0000 414	0.1894 0.0000 666	0.4524 0.0000 511	0.0415 0.0000 617	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501
STN006	1.00000 0.0000 591	0.2677 0.0000 454	0.0332 0.0000 562	0.1170 0.0000 414	0.1894 0.0000 666	0.4524 0.0000 511	0.0415 0.0000 617	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501
STN007	0.0332 0.0000 454	0.2677 0.0000 591	1.00000 0.0000 661	0.0332 0.0000 562	0.1170 0.0000 414	0.1894 0.0000 666	0.0415 0.0000 617	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501
STN008	0.1914 0.0000 562	0.0332 0.0000 454	0.0332 0.0000 562	1.00000 0.0000 661	0.0332 0.0000 562	0.1170 0.0000 414	0.1894 0.0000 666	0.0415 0.0000 617	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501
STN009	0.1170 0.0000 414	0.0415 0.0000 617	0.0000 0.0000 501	0.0332 0.0000 562	0.1170 0.0000 414	0.1894 0.0000 666	0.4524 0.0000 511	0.0415 0.0000 617	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501
STN010	0.1894 0.0000 666	0.0415 0.0000 617	0.0000 0.0000 501	0.0332 0.0000 562	0.1170 0.0000 414	0.1894 0.0000 666	0.4524 0.0000 511	0.0415 0.0000 617	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501
STN011	0.4524 0.0000 511	0.0415 0.0000 617	0.0000 0.0000 501	0.0332 0.0000 562	0.1170 0.0000 414	0.1894 0.0000 666	0.4524 0.0000 511	0.0415 0.0000 617	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501
STN012	0.0415 0.0000 617	0.0000 0.0000 501	0.0000 0.0000 501	0.0332 0.0000 562	0.1170 0.0000 414	0.1894 0.0000 666	0.4524 0.0000 511	0.0415 0.0000 617	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501
STN013	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501	0.0332 0.0000 562	0.1170 0.0000 414	0.1894 0.0000 666	0.4524 0.0000 511	0.0415 0.0000 617	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501
STN014	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501	0.0332 0.0000 562	0.1170 0.0000 414	0.1894 0.0000 666	0.4524 0.0000 511	0.0415 0.0000 617	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501
STN015	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501	0.0332 0.0000 562	0.1170 0.0000 414	0.1894 0.0000 666	0.4524 0.0000 511	0.0415 0.0000 617	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501
STN016	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501	0.0332 0.0000 562	0.1170 0.0000 414	0.1894 0.0000 666	0.4524 0.0000 511	0.0415 0.0000 617	0.0000 0.0000 501	0.0000 0.0000 501	0.0000 0.0000 501

Note: STN 106 = T2
STN 108 = T3
STN 109 = T1
STN 110 = T4
STN 111 = T9



Table A13.2

Factor Analysis of Exceedance Hours
Principal Axis and Varimax Rotated Methods

INITIAL FACTOR METHOD: PRINCIPAL AXIS

PRIOR ESTIMATES OF COMMUNALITY										
	STN005	STN006	STN007	STN008	STN010	STN106	STN108	STN109	STN110	STN111
	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000
EIGENVALUES	3.015631	2.700942	1.038093	0.887018	0.744831	0.489891	0.424987	0.293728	0.207024	0.178810
PERCENT VARIATION	0.303	0.273	0.104	0.089	0.074	0.049	0.043	0.029	0.021	0.018
4 FACTORS WILL BE RETAINED.										
EIGENVECTORS										
	1	2	3	4						
STN005	0.32385	0.29597	0.88810	-0.55530						
STN006	0.42318	-0.12673	-0.73634	0.14813						
STN007	-0.49288	0.12701	-0.12404	-0.86459						
STN008	-0.15301	-0.19501	0.88610	0.19054						
STN010	-0.17221	0.49991	-0.89479	0.23515						
STN106	-0.19424	0.49991	0.10057	-0.49517						
STN108	-0.19424	0.49991	0.10057	-0.49517						
STN109	-0.19424	0.49991	0.10057	-0.49517						
STN110	-0.19424	0.49991	0.10057	-0.49517						
STN111	-0.19424	0.49991	0.10057	-0.49517						
FACTOR PATTERN										
	FACTOR1	FACTOR2	FACTOR3	FACTOR4						
STN005	0.32385	0.29597	0.88810	-0.55530						
STN006	0.42318	-0.12673	-0.73634	0.14813						
STN007	-0.49288	0.12701	-0.12404	-0.86459						
STN008	-0.15301	-0.19501	0.88610	0.19054						
STN010	-0.17221	0.49991	-0.89479	0.23515						
STN106	-0.19424	0.49991	0.10057	-0.49517						
STN108	-0.19424	0.49991	0.10057	-0.49517						
STN109	-0.19424	0.49991	0.10057	-0.49517						
STN110	-0.19424	0.49991	0.10057	-0.49517						
STN111	-0.19424	0.49991	0.10057	-0.49517						
VARIANCE EXPLAINED BY EACH FACTOR										
	FACTOR1	FACTOR2	FACTOR3	FACTOR4						
	3.014633	2.700942	1.038092	0.887018						
FINAL COMMUNALITY ESTIMATES										
	0.841882	0.809829	0.770473	0.820807	0.730844	0.732118	0.830135	0.677168	0.740132	0.805811

NOTE: STN 106 = T2
STN 108 = T3
STN 109 = T1
STN 110 = T4
STN 111 = T9



Appendix 14

The probability distribution function $p(x)$, for a lognormally distributed variable x is given by equation A14.1, in which two parameters are used to characterize the distribution.

$$p(x) = \frac{1}{x\sigma(2\pi)^{1/2}} \exp \left[- \frac{(\ln x - \mu)^2}{2\sigma^2} \right] \quad 14.1$$

The parameters μ and σ are the geometric mean and standard deviation, respectively.

The probability that a lognormally distributed variable is less than a specified value x is given by the cumulative distribution function $F(x)$

$$\text{where } F(x) = \Phi \left(\frac{\ln x - \mu}{\sigma} \right) \quad 14.2$$

Φ is the Gaussian function where

$$\Phi(n) = \frac{1}{(2\pi)^{1/2}} \int_0^n e^{-t^2/2} dt \quad 14.3$$

is the cumulative distribution function for a variable with mean zero and unit standard deviation. Tables of $\Phi(n)$ are readily available.

The quantity of interest here, is the probability that a specified



value is exceeded, $\Pr(C > x)$ and this is given by the complementary distribution function

$$F(x) = 1 - \phi \left(\frac{\ln x - \mu}{\sigma} \right) \quad 14.4$$

Three values of x are selected namely 210, 105 and 75 ppb hence the quantities of interest are the probabilities that these values are exceeded each year. These quantities are labelled N_{210} , N_{105} , and N_{75} . Once the parameters μ and σ are known, then N_{210} , N_{105} and N_{75} may be calculated.

The other quantity that will be estimated is $x_{.01}$ - the hourly NO_2 level which will be exceeded 0.01 % of the time, i.e. about one per year. Equation 14.5 indicates how this is calculated.

$$x_{.01} = \exp [\sigma \phi^{-1}(0.999) + \mu] \quad 14.5$$



REFERENCES

Concord Scientific Corporations (1982). Final Report. Vancouver Oxidant Study. Air Quality Analysis. Prepared for Environment Canada. DSS Contract 47SSKE145-1-0519.

Georgopoulos, P.G., Seinfeld, J.H. (1982). Statistical Distributions of Air Pollutant Concentrations. E.S. & T. 16, 401A.

